The Task & Finish Group Report on

Industry Resilience for Critical Minerals

An analysis of sector risks and recommendations for the UK's supply chain resilience

19 December 2023

Foreword

Critical minerals and metals are essential to modern life.

We depend on them for our alarm clocks, our morning cup of tea, our smartphones and even the paint on our walls; and that is before we have even left the house. We rely on them far more that many people realise.

As a nation, we need the right materials if we are to make our transition to a clean net zero economy: the lithium, nickel and cobalt for our electric car batteries; the gallium and germanium for the all-important semiconductors in our laptops; and the copper for our expanding electricity grid infrastructure.

That requirement means it is imperative the UK has resilient and secure critical mineral supply chains, but supply is not a given and the UK is not alone in its needs.

As nations around the world reduce fossil fuel use in favour of more sustainable energy sources, the metals we need, and the critical minerals from which they are refined, will be increasingly in demand. The UK does not have its own resources for some minerals, and we have already seen the disruption to supply chains caused by war. If we fail to act with speed there will be consequences, both in the short- and long-term, from supply chain failures to offshoring.

That is why the Minister for Industry and Investment Security, Nusrat Ghani MP, convened our Independent Task & Finish Group on Industry Resilience for Critical Minerals to investigate the critical mineral dependencies, our vulnerabilities, and our prospects for the future.

Working with UK industry from all sectors, we have been able to understand the sum of our collective material needs and design a framework to monitor critical mineral risk.

The report highlights the varying risks of different critical minerals and critical mineral-reliant industries, such as the automotive, electronics, aerospace, and renewable energy sectors. This includes the key points of tension that could lead to instability and disruption, as well as those opportunities which rely on supplies of critical minerals to come to fruition.

Of course, the risk assessment framework is only as strong as the data available. Some of the dependencies may not accurately reflect the exact nature of the risk of a specific mineral due to the quality of data, but the risk assessment is a starting point that it is indicative of broad trends, and from which we can draw conclusions and make clear recommendations.

Because where risks exist, opportunities follow shortly thereafter.

Securing the UK's critical minerals cannot be viewed as an exercise in risk mitigation only. With resilient critical mineral supply chains, the right cross-sector incentives, and wide-reaching collaboration between government and business, the UK can create a thriving sustainable economy that is fit for the future.

Katherine Bennett

Chief Executive Officer, High Value Manufacturing Catapult

Acknowledgments

This report was completed on behalf of the Task & Finish Group on Industry Resilience for Critical Minerals (T&F Group). The T&F Group is chaired by Katherine Bennett, and the Vice-Chair is Colin Church. The members of the T&F Group are as follows:

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- **Chris Hewett,** Solar Energy UK

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The Deloitte team included Gabriela Borzynska, Neil Bourke, Caitlin Cox, Pierrick Drapeau, Thorben Heidrich, Bethany Jayasinghe, Aniththa Jeyakumaran, Neelam Melwani, Pim Oudejans, James Pennington, Izzy Richards, Hannah Routh, Marcus Shonfield and others.

The Green Alliance team included Emily Carr, Jasmine Dhaliwal, Libby Peake and Heather Plumpton.

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Executive Summary

The Task & Finish Group on Critical Mineral Resilience for UK Industry was brought together by the Minister for Industry and Investment Security, Nusrat Ghani MP, to investigate the critical mineral dependencies and vulnerabilities across UK industry sectors, support UK industry to promote resilience and diversity in its supply chain and design a framework for monitoring and mitigating critical mineral supply risk across UK industry sectors. This report includes: a series of recommendations for UK Government and Industry; insights on the risks impacting six sectors identified by the Department for Business and Trade – Aerospace and Defence, Automotive, Chemicals, Electronics, Energy, and Medical Technologies (MedTech); and an overview of the future trends. Alongside the overarching recommendations, members have also developed targeted recommendations considering specific critical raw material (CRM) requirements and supply vulnerabilities that exist within each sector.

CRMs have become important inputs into the goods and services we use in our everyday lives, with a trend that will see the demand only increase. For example, the UK's energy transition towards net zero by 2050 (as set out in the Climate Change Act 2008) will be underpinned using CRMs throughout, from electric vehicles to wind turbines. Understanding the role that CRMs play in UK industry at different stages of the value chain further highlights the importance they have in our economy.

The work of the Task & Finish Group identified that a key area of strength for the UK is in the midstream of CRM value chains, as well as the opportunity to increase material circularity. This is highlighted through several of the recommendations, calling on the UK Government to support positioning the UK as a global leader in this space. This would aid the UK's net zero ambitions, both allowing the efficient delivery of infrastructure projects requiring extensive CRM input, while also building resilience in the UK supply chain through a continuity of supply from existing products in circulation within the UK economy.

The complexity of CRM supply chains, which are global in nature, has exposed them to increasing geopolitical tensions. As a result, the UK Government has been looking at how to address the UK's CRM risks and vulnerabilities while large-scale industry players have spent significant resources looking at the criticality of their supply chains to assess potential areas of supply constraints. The geographical concentration of many CRM supply chains has further raised the risk of supply bottlenecks in the face of growing protectionist behaviour and trade restrictions.

While the geological occurrence of minerals and metals will fundamentally constrain the extent to which UK industry can diversify primary supply of CRMs domestically, actions have nonetheless been taken to bolster UK supply chains and protect businesses from supply side shocks. This report has identified three areas that can further enhance the UK's resilience – research and innovation, supply chain transparency, and applying circularity principles.

As the Task & Finish Group looked at building resilience in the UK supply of CRMs it also considered the increasing environmental and social impacts that CRM extraction and processing have, which are becoming increasingly important given regulatory requirements and societal expectations. This is reflected in the Risk Framework, which recognises that building a resilient supply chain for CRMs cannot come at the expense of environmental sustainability, equitable societies, and accountable governance.

How to navigate this Report

- This report has been developed by the T&F Group members to provide recommendations to the UK Government on how to enhance the UK's resilience to CRMs. To achieve this outcome, the report provides an overview of the work done to date on CRMs and expectations of the T&F Group before going into detail on the risk assessment relevant to each of the priority sectors.
- The report covers six priority industry sectors along with a cross-cutting sector risk assessment. Should you be looking for specific industry trends, these sections will be most useful.
- The report concludes with seven recommendations for the UK Government and industry to take forward to enhance the UK's supply chain resilience of CRMs.

Cross-cutting sector supply and ESG risk assessment

In developing a risk assessment to assess the dependencies of each sector by each individual mineral, a framework was developed to assess the implications from both a supply and ESG risk perspective. The reason for disaggregating this way is to allow for a granular understanding of the risks. This scoring allows for a better understanding of the interaction between ESG and supply risk. Figure 1 provides an aggregate view of the assessment across each of the sectors with additional information set out in the individual sector focused chapters in this report. For further information on the methodology for the risk assessment and data sources used, please see Appendices 2 and 3.

Cross-Cutting Sector Risk Assessment

Mineral	Aerospace & Defence		Automotive		Chemicals		Electronics		Energy		Med Tech	
	ESG Risk	Supply Risk	ESG Risk	Supply Risk	ESG Risk	Supply Risk	ESG Risk	Supply Risk	ESG Risk	Supply Risk	ESG Risk	Supply Risk
Cobalt	3.3	4.3	3.3	4.1	3.3	4.3	3.3	3.3	3.3	4.3	3.3	4.3
Copper	2.8	3.2	2.8	3.4	2.8	3.0	2.8	3.5	2.8	3.5		
Gallium	2.7	4.7	2.7	4.2			2.7	4.7	2.7	4.5	2.7	4.2
Lithium	2.8	3.6	2.8	4.1	2.8	3.6	2.8	4.1	2.8	3.6	2.8	4.1
Nickel	3.6	3.8	3.6	3.8	3.6	3.8	3.6	3.0	3.6	3.8		
Platinum	3.6	3.8	3.6	3.7	3.6	4.1	3.6	3.7	3.6	4.1	3.6	4.0
REE	2.9	3.9	2.9	3.9	2.9	3.6	2.9	4.0	2.9	4.0	2.9	4.0
Silicon	2.9	3.5	2.9	4.0	2.9	4.2	2.9	4.5	2.9	4.5	2.9	4.5
Tantalum	3.5	4.3					3.5	4.1	3.5	3.7	3.5	4.2
Titanium	2.9	3.7	2.9	2.9					2.9	3.3		

ESG Risk Level: 1 (Low Risk) – 2 – 3 – 4 – 5 (High Risk)
Supply Risk Level: 1 (Low Risk) – 2 – 3 – 4 – 5 (High Risk)
Not assessed

Figure 1: Cross-cutting sector risk assessment

Overarching recommendations

The following overarching recommendations from the T&F Group were developed to provide concrete follow up actions for both the UK Government and industry, to increase CRM resilience both now and through to 2050.

1. Develop a long-term vision on industry resilience that includes CRMs for the UK
2. Enhance CRM supply chain transparency though improved data availability to support decision making
3. Build on the UK's competitive advantages and develop its midstream economy
4. Take a shared approach between Government and Industry to build a robust circular economy for CRMs
5. Implement strategic international partnerships, trade deals, friend shoring
6. Adopt a holistic approach to assess the environmental and social impacts of CRM supply chains
7. Support UK skills and innovation development

For further detail on the recommendations please refer to the Recommendations section of this report.

02 Introduction and context

Introduction and objectives

The Task & Finish Group on Industry Resilience for Critical Minerals (T&F Group) was commissioned by the Department for Business and Trade in its Critical Mineral Refresh paper as one of the steps Government was taking to support the delivery of the UK's Critical Minerals Strategy. The T&F Group consists of representatives drawn from six key industry sectors that are dependent on critical minerals, including Aerospace and Defence, Automotive, Chemicals, Electronics, Energy, and MedTech, as well as representatives from the mining and processing sector and the wider supply chain.[1] The T&F Group was established to provide the UK Government with guidance and expertise on existing vulnerabilities and dependencies in the UK's critical minerals, metals, and materials supply chains, and to offer recommendations on how Government and industry can enhance security of supply and boost supply chain sustainability and resilience.

UK industry sectors have a broad range of critical mineral, metal, and material dependencies based on where their operations sit in the value chain. In this report, these critical minerals, metals, and materials will be collectively referred to as critical raw materials (CRMs) as an all-encompassing term for the mix of critical resources that the UK economy relies on. This includes unprocessed materials and intermediate minerals and metals used in mid-stream processing and alloy production. We have set out in more detail the CRMs assessed in this report in Appendix 1. To achieve its objectives, the T&F Group conducted four cross-sector workshops throughout 2023, along with supplementary sector-specific workshops. In addition, a quantitative industry risk assessment was developed to identify dependencies, risks and impacts at a material and industry level; an industry survey was conducted; and a series of interviews were held with T&F Group members and other industry stakeholders.

The remit of the risk assessment was solely focused on the six sectors in scope rather than the UK as a whole and does not seek to replicate the criticality assessment completed by the British Geological Survey (BGS). Instead, it aims to complement the ongoing research of the BGS, and its Critical Minerals Intelligence Centre (CMIC) programme funded by the Department for Business and Trade that will use primary data to assess the criticality of various metals and minerals to the UK on a regular basis.

The report is structured as follows:

- A cross-sector and sector-by-sector risk analysis that outlines the key dependencies and risks associated with the supply of CRMs, including the evolution of risks and sector-specific recommendations;
- An assessment of industry resilience;
- A vision for future UK resilience;
- A breakdown of future trends; and
- Overarching recommendations to UK Government and industry.

[1] Department for Business and Trade and Nusrat Ghani MP, "Government ramps up supply chain work with first independent Critical Minerals Taskforce meeting," UK Government, April 20, 2023.

Context

In July 2022, the UK Government published its Critical Minerals Strategy to strengthen the country's CRM supply chain resilience. In March 2023, the Government issued a Critical Minerals Refresh, that sets out an updated approach to delivering the Strategy, in light of a changing global landscape and sharpening geopolitical competition. The Strategy and the Refresh highlight the UK's critical mineral strengths, such as mining and mineral expertise, midstream processing and manufacturing, research and development, finance and standards, as well as being home to mining multinationals. Along with leveraging its key strengths, the Refresh highlights that it will not be possible (or desirable) for the UK to onshore all aspects of critical minerals supply chains, and rather Government and industry should focus on the need to build resilient global supply chains with a diverse supply base rooted in open global markets and an effective trading system.[2] In its Refresh, the Government also launched the T&F Group and mandated this report. The T&F Group is composed of experts and industry leaders appointed by, and reporting directly to, the Minister for Industry and Investment Security. Their objectives were "to investigate the critical mineral dependencies and vulnerabilities across UK industry sectors, support UK industry to promote resilience and diversity in its supply chain and design a framework for monitoring and mitigating critical mineral supply risk across UK industry sectors."[3] The T&F Group has delivered their findings within this report.

The Strategy and the Refresh are underpinned by three overarching objectives: (1) to accelerate the UK's domestic capabilities, such as those highlighted above; (2) to collaborate with international partners; (3) and to enhance international markets.[4]

As part of the Strategy's launch, BGS carried out a criticality assessment to determine a list of the UK's most critical minerals.[5] Their assessment defines mineral criticality based on risk of global supply disruption and level of importance to the UK economy. CRM criticality is defined in a similar way for this report: they are the minerals, metals, and materials essential to the UK's economic and national security, with a high risk of supply chain vulnerability or disruption. The list of critical minerals identified by the BGS criticality assessment are:

Antimony	**Lithium**	**Silicon**
Bismuth	**Magnesium**	**Tantalum**
Cobalt	**Niobium**	**Tellurium**
Gallium	**Palladium**	**Tin**
Graphite	**Platinum**	**Tungsten**
Indium	**Rare Earth Elements (REEs)**	**Vanadium**

In corroboration with BGS, the Government's Critical Minerals Expert Committee were asked to provide a 'watchlist' of minerals, defined by potentially increasing levels of criticality.[6] These include iridium, manganese, nickel, phosphates, ruthenium.

The scope of CRMs assessed in this report includes all those examined as part of the BGS criticality assessment, alongside the Critical Minerals Expert Committee's watchlist, as well as any others highlighted by T&F Group members during the series of workshops.

[2] Department for Business & Trade and Department for Business, Energy & Industrial Strategy, "Critical Minerals Refresh: Delivering Resilience in a Changing Global Environment," UK Government, March 13, 2023.

[4] Department for Business & Trade and Department for Business, Energy & Industrial Strategy, "Resilience for the Future: The UK's Critical Minerals Strategy," UK Government, March 13, 2023.

[5] Paul Lusty et al., "UK criticality assessment of technology critical minerals and metals" British Geological Survey, 2021.

[6] BEIS (2022), Critical Minerals Expert Committee

03

Risk assessment summary and core findings

Risk assessment summary and core findings

This section of the report is broken down into cross-cutting risks and dependencies, and then sector-specific sections. It aims to highlight the minerals and metals with the greatest supply chain risks from an original equipment manufacturer (OEM) and end-user perspective, based on the risk assessment and supplementary research. The quantitative risk assessment uses more than 20 databases and survey data with the aim of creating a picture of the material risks in the supply chain at both an industry-specific and cross-industry level (see risk methodology approach and limitations in Appendix 2 and 3 for further information on the database breakdown).[7] The indicators in the risk assessment are broken down into three areas:

Mineral or metal importance

This shows a sector's dependency on a given mineral or metal and represents the potential impact that supply chain disruption could have on sector output. This data was gathered directly from the T&F Group members and other industry representatives.

Supply risk

The supply risk associated with a given material represents the likelihood that supply chains are disrupted due to a range of factors including, for example, mining and processing concentration or political stability in a source country.

Environmental and social risks

This represents the risk relating to the impact that a given material's supply chain has on the environment and society, such as on water pollution or biodiversity; or risks of child and forced labour in the value chain.

The analysis in this report is based on findings from the initial quantitative risk assessment, cross-sector and sector-specific workshops, stakeholder interviews, and industry surveys. While the latter three sources are derived from qualitative primary UK industry input, the risk assessment relied on publicly available data sources. The risk assessment framework provides a foundation that can be built upon as data is enhanced and is designed to provide actionable insights to industry but not a final picture. Data quality is often highly varied, incomplete and/or inconsistent. Through enhancing this data, UK Government and industry will gain a better understanding of the risks facing CRM supply chains and a key recommendation in this report focuses on improving data availability and quality.

[7] The methodology follows a customised version of the methods put forward by Graedel. T https://cie.research.yale.edu/research/criticality-metals. The risk assessment has some key limitations including data availability and quality (see methodology in appendix). The assessment aims to provide actionable insights to government and companies and is backed up by qualitative findings which supplement the analysis and are called out in the body of the report. A key finding of this report is the need for better data across CRM supply chains pertaining to supply and ESG risks.

Cross-sector risks and dependencies

The six sectors represented on the T&F Group have a broad range of CRM dependencies that are key to the UK economy. These are highlighted individually in the sector specific sections. However, applications for certain CRMs have been identified in multiple sectors, meaning that UK industry has a greater overall dependency on these CRMs. These CRMs will be referred to as cross-cutting dependencies in this report, with risks that apply to large portions of industry, as well as a set of environmental and social risks that are embedded in CRM supply chains. This section highlights these cross-cutting dependencies, and explores the supply and ESG risks, their technology applications, and highlights key considerations for companies in their supply chains.

Cross-cutting sector dependencies

To identify the core cross-cutting sector dependencies in UK industry, an analysis was completed into the CRMs used by each sector. This was based on the findings of T&F Group workshops, surveys, and interviews. This analysis was used to determine a list of the top 10 most important CRMs in UK industry and the key types of risks present in the value chains of these CRMs. These top 10 CRMs can be seen in Figures 2, 3, and 4 below. There will be a difference in the CRMs assessed in this report compared with those included in BGS's criticality assessment of technology critical minerals and metals given the differing criteria (this report shows risks per industry and BGS's report will give a full UK perspective used to identify the relevant CRMs, the combination of these reports will provide the Government with a clearer identification of the priorities when it comes to developing policy.

Figure 2 shows the spread of CRM dependencies across the six T&F Group sectors and provides a non-exhaustive list of examples of applications. More detail on mineral use by sector is provided in throughout the sector analysis chapter.

	Key applications	Aerospace and defence	Automotive	Chemicals	Electronics	Energy	MedTech
Cobalt	*Superalloys; battery cathodes; solid oxide electrolysers*	●	●	●	●	●	●
Platinum	*Catalytic converters; hydrogen fuels cells; industrial catalysts; PEM electrolysers; chemotherapy*	●	●	●	●	●	●
REEs	*Permanent magnets; electric motors; electronic sensors; nuclear reactor control rods; wind turbine generators; medical lasers and imaging*	●	●	●	●	●	●
Lithium	*Battery cathodes; nuclear moderator material; medical implant batteries*	●	●	●	●	●	●
Silicon	*Battery anode doping; semiconductors; nuclear fuel cladding; solar cells*		●	●	●	●	●
Nickel	*Superalloys; speciality steels; battery cathode; nuclear fuel cladding*	●	●	●		●	●
Gallium	*Communication devices; radar systems; semiconductors (incl. Wide bandgap); thin-film solar cells; sensors; medical imaging devices*	●	●	●	●	●	
Copper	*Electric motors; electrical wiring; semiconductors; electrical infrastructure; wind turbine drivetrain*		●	●	●	●	
Tantalum	*Superalloys for turbine blades; capacitors for electronic circuits; Pacemakers*	●			●	●	●
Titanium	*Structural components in aerospace; nuclear energy fusion armour*	●	●			●	

Figure 2: Cross-cutting sector dependencies

Key: ● Applicable

Cross-cutting CRM supply risks

Figure 3 outlines the risk profile of the CRMs with the highest cross-sector dependencies based on the findings of the risk assessment. The dots indicate the areas where a CRM has the greatest risk exposure that could lead to supply chain disruption (for more information on the taxonomy of risks see the risk register on page 18).

	High mining concentration	High processing concentration	Net import reliance	Regulations and sanctions	Weak governance	Price volatility	Low recycling rates	Companion metal fraction
Cobalt	●	●	●		●	●		●
Platinum	●	●		●	●			No Data
REEs	●	●	●			●	●	
Lithium	●	●	●			●	●	
Silicon	●	●	●		●		●	
Nickel			●	●	●	●		
Gallium	No Data	●	●		●	●	●	●
Copper			●	●				
Titanium			●			●		
Tantalum	●		●		●		●	

Figure 3: Cross-cutting CRM supply risks

Key: ● Applicable; (grey cell) No Data

The supply risks for these cross-sector CRM dependencies share a common theme; high reliance on international supply chains with limited diversification of suppliers. This includes:

- Heavy reliance on imports as often assessed to have little domestic supply (except for platinum where significant supply of recycled material exists);
- High concentration of mining and/or processing capacity in one country, for example China which tops mining and processing output for 14 and 20 materials on the UK's list respectively; and
- High reliance on countries that may score poorly based on governance and may be politically unstable.

Each mineral carries different risks. For example, battery materials (e.g., lithium, cobalt, nickel, manganese, graphite, and copper) alongside REEs face a greater level of reliance risk in comparison to platinum-group metals (PGMs). PGMs face alternative risks such as unfavourable trade policy and insufficient capital investment.[8] In the short- to medium-term[9] these risks may lead to challenges for UK industry as it seeks to maintain continuity of supply in increasingly challenging international markets. Rising geopolitical tensions, as well as regulation and sanctions, have increasingly complicated CRM supply chains. For example, China has indicated its willingness to continue to apply export controls on CRMs in the latter half of 2023,[10] and the UK maintains import duties on Russian metals and minerals in response to the invasion of Ukraine.[11]

[8] Task & Finish Group Member Interview, October – November, 2023.
[9] Short term: 1-5 years, medium term: 5-10 years, long term: 10+ years.
[10] China has placed export controls on Gallium, Germanium and Graphite in the last year. Reed Blakemore, "What to make of China's latest restrictions on critical mineral exports," Atlantic Council, October 26, 2023.
[11] The UK placed import duties on copper, lead, aluminium, and nickel in 2022.

An evolving world could leave UK industry exposed to supply chain disruption, with few viable alternatives to diversify supply. Building the UK's CRM alliances and supply chain agreements and guarantees from producer countries are seen as key pillars to sheltering UK industry from evolving geopolitical tensions and trade restrictions.

Cross-cutting CRM ESG risks

Figure 4 outlines the key ESG risks associated with the CRMs that have the highest cross-sector dependencies, based on the findings of the risk assessment. The dots indicate the areas where a CRM has the greatest ESG risk exposure. For more information on the risks, please see the risk register on page 18.

The risk framework aims to provide actionable insights to industry on the types of risks they should be monitoring in their supply chain, based on the best available public data. However, there are limitations, with the primary one being the lack of mining specific data that covers a broad range of CRMs on critical ESG impacts, such as the impact on water tables and pollution. For the purposes of this analysis, water and ecosystem data are measured at a mining or mining and processing country level, whereas biodiversity and carbon dioxide (CO_2) emissions are measured at a per material level. Therefore, this could be seen as a starting point, but it is recommended that all firms consuming CRMs should set up their own processes around supply chain due diligence and ESG risks.

	Water pollution	Water depletion	Water scarcity	Ecosystem loss	Biodiversity	Child labour	Forced labour	CO_2 emissions
Cobalt		●		●		●		
Platinum			●	●	●			●
REEs		●		●	●			No Data
Lithium				●	●			
Silicon		●		●	●			No Data
Nickel	●	●		●	●		●	
Gallium	●	●		No Data	No Data			
Copper					●			
Titanium				●	●			
Tantalum	●	●		●		●		

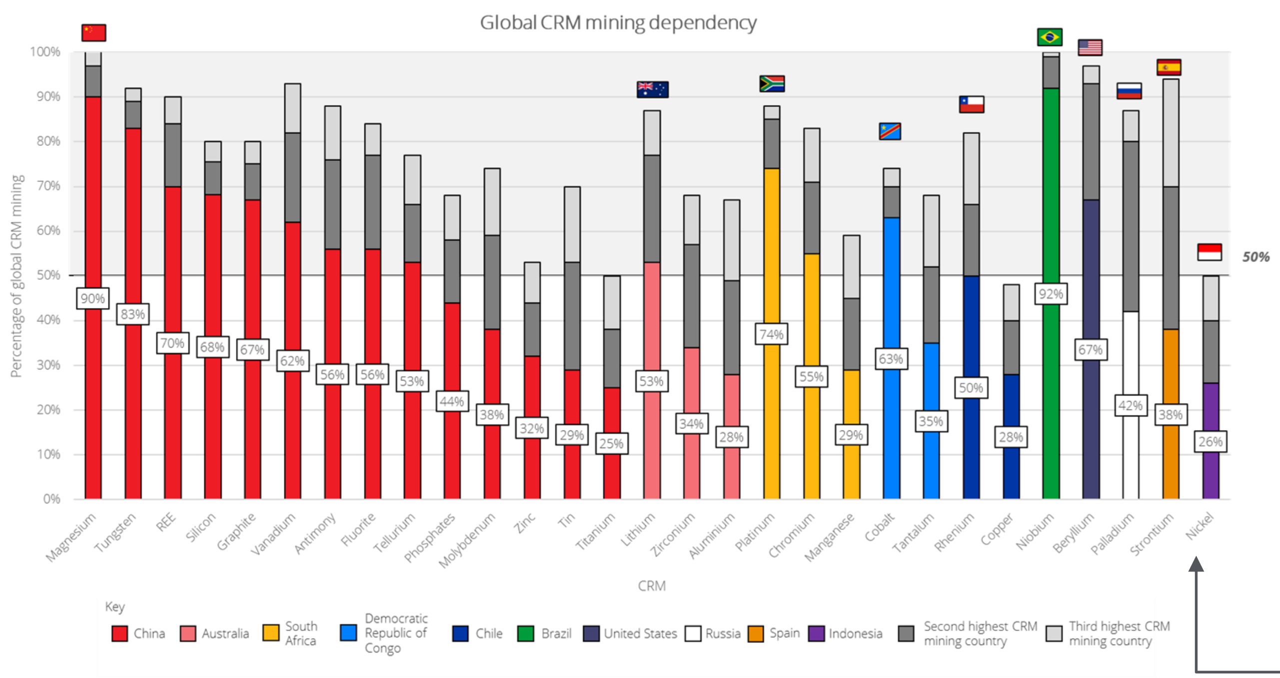
Figure 4: Cross-cutting CRM ESG risks

Key: ● Applicable ▒ No Data

One clear opportunity for better data would be CO_2 -related information. The data in this framework dates from an older source and needs updating. A useful study would be to examine the cradle-to-gate emissions of different materials and provide ranges from the least to the highest emissions, depending on the energy or process used for processing, or processing country. In the near future this could be augmented with a large set of real-world data based on the battery passport legislation, which requires a CO_2 LCA for all new batteries. Following CO_2, LCAs could be carried out looking more specifically at other impact categories including some of those listed in the above tables. Having public access to this type of general data would greatly help industry to better shape their strategies around supply chain due diligence and ESG.

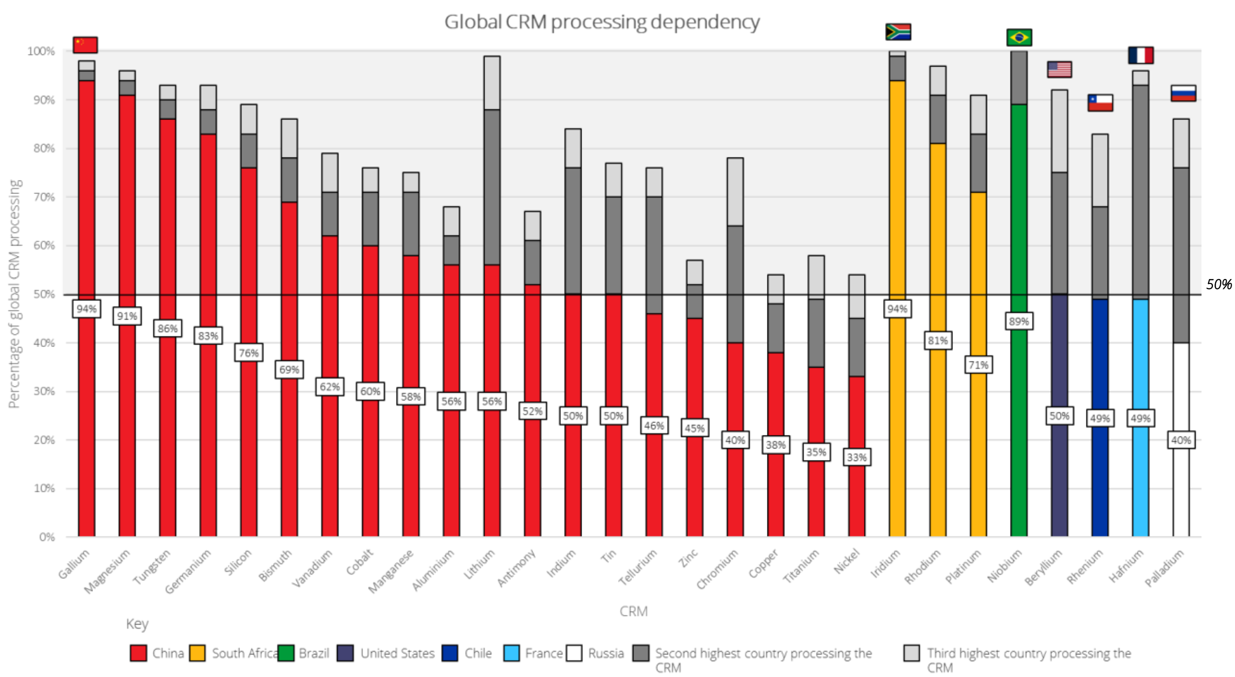
Top CRM Miners and Processors

Global CRM supply chains are highly concentrated in specific geographies, both at the mining and processing stages, meaning there is currently limited opportunity for downstream buyers to diversify supply. This concentration is considered in risk registers throughout the report, but the specific producer countries are highlighted in Graph 1 and Graph 2 below.



Graph 1: overview of top CRM mining countries globally shown with a coloured bar the percentage mined in the leading country denoted with a flag and the percentage mined in the next two largest countries[12 13]

> There are significant data discrepancies between different sources for mining concentration. EU data[12] states that Indonesia mines 26% of nickel; US data[13] states it is roughly half of global supply at 48%.



Graph 2: Overview of top CRM processing countries globally shown with a coloured bar the percentage processed in the leading country denoted with a flag and the percentage processed in the next two largest countries[14 15 16]

[12] Publications office of the European Union, "Study on the critical raw materials for the EU 2023," European Commission, 2023.
[13] U.S. Geological Survey, "Mineral Commodity Summaries 2023," U.S. Geological Survey, January 31, 2023
[14] Publications office of the European Union, "Study on the critical raw materials for the EU 2023," European Commission, 2023
[15] U.S. Geological Survey, "Mineral Commodity Summaries 2023," January 31, 2023
[16] Christina Lu, "America Dropped the Baton in the Rare-Earth Race," Foreign Policy Magazine, June 23, 2023.

Risk Register

Supply risk register

Each sector in scope for this report is subject to a different set of supply chain risks which vary depending on the CRMs upon which they rely. This means each industry and material has a differing risk profile (see industry chapters). A comprehensive list of, and introduction to, all the different types of risks inherent in CRM supply chains can be found in the risk register below, which is designed to provide a taxonomy of risks which apply in varying degrees to different industries and materials.

However, the risk presented by geopolitical tensions is distinct from others mentioned in the risk register in that it embodies a broader range of risk categories. The International Renewable Energy Agency (IRENA)[17] outlines that geopolitical risk comprises six sub-sections,[18] all of which have the potential to disrupt UK CRM supply chains in different ways. These risks are embedded within the other risk types highlighted below in Figure 5.

Risk type	Risk description
High import reliance	Reliance on global markets has advantages including promoting economically efficient production, however a high import reliance for CRMs can leave industry vulnerable to supply-side shocks, such as those linked to market manipulation, geopolitical tensions, and trade restrictions.[19] As an island nation with very limited resource deposits, these are risks that the UK will need to manage, as it cannot become self-sufficient in CRM supply chains and will always have a high degree of import reliance.[20] Risks associated with import levels vary based on the specific mineral or metal and its supply chain, meaning that the potential for disruption is not universal. There are also logistical challenges linked to a high import reliance, such as the freight and shipping disruption seen in recent years, leading to delays in supply.[21]
High mining concentration	CRMs with a high mining concentration are often characterised by tight supply chain bottlenecks, offering limited opportunity for midstream processors to diversify supply.[22] While mining companies are working to discover and develop new extraction opportunities, IEA analysis shows that an average mining project takes 16 years to develop.[23] This long lead time means that high mining concentrations will likely persist as a risk across most CRMs in the short- to medium-term. Geological limitations also need to be considered; only 0.1% of mineral exploration projects become mines,[24] meaning there is a risk that most extraction opportunities cannot be developed.[25] Further, extreme weather events, such as flooding, can disrupt operations in existing mines, increasing the vulnerabilities of a high mining concentration,[26] while resource nationalism can increase state control over the mining and resource ownership, creating disputes over royalties.[27]
High processing concentration	CRMs with a high processing concentration, like those with a high mining concentration, are often characterised by tight supply chain bottlenecks, offering limited opportunity for downstream consumers to diversify supply.[28] At present, this concentration is greater for processing than for mining. However, unlike mining sites, processing sites are not as geographically constrained,[29] and have shorter lead times. While this means that there may be more opportunity for midstream and downstream industries to diversify supply in the future, processing capabilities are complex and challenging to develop, and often span multiple stages, meaning a broad range of specialised infrastructure is needed to reduce global processing concentration.

National policies (e.g. export restrictions, nationalisation, or strong partnerships with specific countries) and approaches to business (e.g. Australia's dig-and-ship) shape the relationship between mining concentration and processing concentration.[30]

[17] IRENA, "Geopolitics of the energy transition: Critical materials," International Renewable Energy Agency, 2023.
[18] 1. External shocks (i.e. wars); 2. Resource nationalism (i.e. expropriation); 3. Export restrictions (i.e. export quotas); 4) Mineral cartels (i.e. coordination of production volumes); 5. Political instability and social unrest (i.e. corruption); 6. Market manipulation (i.e. short squeezing.)
[19] IEA, "Critical Minerals Policy Tracker," International Energy Agency, 2022.
[20] Critical Minerals Association, "Written evidence submitted by the Critical Minerals Association (MIN0015)," UK Parliament, February, 2023.
[21] Mohammad Asghari, Mohamad Jaber and Mirzapour Al-e-hashem, "Coordinating vessel recovery actions: Analysis of disruption management in a liner shipping service," European Journal of Operational Research, June 1, 2023.
[22] IEA, "Ensuring supply reliability and resiliency," International Energy Agency, 2022.
[23] IEA, "Promoting exploration, production and innovation," International Energy Agency, 2022
[24] Leena Suopajärvi et al., "Social aspects of business risk in the mineral industry—political, reputational, and local acceptability risks facing mineral exploration and mining," Mineral Economics, 12 September, 2022.
[25] Lukas Rüttinger, Pia van Ackern andTimon Lepold, "Impacts of climate change on mining, related environmental risks and raw material supply," Ressortforschungsplan of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, June, 2020.
[26] ibid.
[27] IRENA, "Geopolitics of the energy transition: Critical materials," International Renewable Energy Agency, 2023.
[28] IRENA, "Ensuring supply reliability and resiliency," International Energy Agency, 2022.
[29] Josh de Maio, "Why Inflation Reduction Act subsidies should differentiate between critical mineral mining and process," Manufacturing Dive, November 7, 2023.
[30] Task & Finish Group Member Interview, October – November, 2023.

Risk type	Risk description
Weak national governance in supplier countries	Challenges to governance in mining and processing countries can include government abuse of power, corruption,[31] and uncertainty around government policy.[32] This can lead to market volatility and increase operational uncertainty in supplier countries;[33] adversely affecting continuity of supply for downstream buyers and posing a significant risk. It can also deter new investment in certain geographies.
Regulations and sanctions	CRM regulations and sanctions create risk for industry in two ways: they establish supply chain restrictions;[34] and they introduce compliance challenges for businesses.[35] The most common types of regulations and sanctions seen in mineral and metal supply chains are export controls. The consequences of these measures could include the termination of existing supply chains, and the requirement for businesses to adapt their sourcing strategies, both of which come at a cost to industry. Export controls can also deter investment in processing infrastructure across importer countries and reduce project feasibility.[36] While import controls can create supply chain risks by restricting trade, they are seen as more transparent and predictable than export controls,[37] and their implementation is determined by the UK Government rather than a foreign power.
Geopolitical tensions[39]	The evolving geopolitical landscape and its impact on resource markets has changed the outlook of CRM supply chains in recent years. IRENA identifies six core risks to supply chains in the short- to medium-term:[40] external shocks, resource nationalism, export restrictions, mineral cartels, political instability, and market manipulation. The impact of these could be sudden and widespread, harming operations across all sectors.
High price volatility	High price volatility for commoditised CRMs, such as lithium and cobalt, is closely linked to demand and supply forces in global markets.[41] This has meant that as EV demand increased between 2020-2022, so did the prices of battery metals (battery-grade lithium increased by 500%+, and cobalt by 95%).[42] Equally, as demand has subsided with a worsening economic outlook in 2023, so have market prices (lithium down 75%, cobalt down 50%+ as of November).[43] Both these types of price volatility present risks for buyers and investors. Higher prices increase production costs for manufacturers, which can risk hampering demand for green technologies if costs are passed on. Meanwhile, lower prices can put at risks the financial returns of CRM infrastructure investments, thereby impeding the creation of new diverse supply chains.[44] Price volatility for minor metals can differ to commoditised materials. Minor metals do not always follow market fundamentals in the same way as commoditised CRMs, making prices less predictable. There is also a heightened risk of market manipulation in the supply of these CRMs.[45]
Companion metal fraction	Companion metal fraction refers to the CRMs that are extracted as a secondary product of a primary mineral or metal mining project.[46] These CRMs are often not economically viable to mine independently, such as iridium which is mined with more common PGMs (eg., platinum and palladium). As such, it is difficult to upscale production of these minerals and metals to meet market needs without a corresponding increase in demand for primary minerals or metals.
Low recycling rate	A low recycling rate for CRMs can compound many of the supply risks highlighted in this table by maintaining high industry dependence on virgin minerals and metals. This could leave UK industry exposed to supply chain disruption for longer periods in the future and impede the creation of domestic and diversified closed-loop supply chains.[47] However, while recycling CRMs will play a central role in promoting the UK's supply chain resilience, industry will likely still require virgin minerals and metals for specialist applications in the future.

> Alongside the risk register, each material has its own set of unique risks. For example, one interviewee noted that the main risk facing PGM supply is the lack of incentives supporting capital investment in South African mining and the top risk for UK PGM supply chains is post-Brexit trade policy.[38]

Figure 5: Cross-sector supply risk register

[31] Resource Governance, "Preventing Corruption in Energy Transition Mineral Supply Chains," Accessed October-November, 2023.
[32] Xianhang Qian and Shanyun Qiu, "Preventing Corruption in Energy Transition Mineral Supply Chains," Journal of International Money and Finance, October 2023.
[33] Ari Aisen and Francisco Jose Veiga, "How Does Political Instability Affect Economic Growth?," International Monetary Fund, January 2011.
[34] Nic Fildes and Harry Dempsey, "Mining tycoons battle over lithium's 'corridor of power' in Australia," Financial Times, November 27, 2023.
[35] OECD, "Supply of critical raw materials risks jeopardising the green transition," OECD, April 11, 2023.
[36] Task & Finish Group Member Interview, October - November 2023.
[37] Jane Korinek, "Trade restrictions on metals and minerals," Resource Trade.Earth, July 23, 2018.
[38] Task & Finish Group Member Interview, October - November 2023.
[39] Geopolitical tensions was not an indicator used in the risk assessment, however, it was surfaced as a core risk by T&F Group members.
[40] IRENA, "Geopolitics of the energy transition: Critical materials," International Renewable Energy Agency, 2023.
[41] Kazi Sohag, Yulia Sokolova, Šárka Vilamová, Dmitri Blueschke, "Volatility transmission from critical minerals prices to green investments," Resources Policy, March 21, 2023.
[42] Kazi Tom Moerenhout, Lilly Yejin Lee & James Glynn, "Critical Mineral Supply Constraints and Their Impact on Energy System Models," Center on Global Energy Policy, June 12, 2023
[43] Erik Norland, "Battery Metals Prices are Falling. Will Demand Catch up to Supply?," Open Markets, November 10, 2023.
[44] Task & Finish Group Member Interview, October - November 2023.
[45] ibid.
[46] Thomas Graedel et al., "Methodology of Metal Criticality Determination," Environmental Science & Technology, December 13, 2021.
[47] UK Mission Geneva" Future-Proofing the Supply of Critical Minerals for Net-Zero Emissions," January, 2022.

Environmental and social risk register

The identification and mitigation of supply risks are vital for the resilience of UK industry. However, CRMs carry another set of material risks, namely those pertaining to their impact on the environment and society. This risk assessment, therefore, also identified environmental and social risks in CRM supply chains as seen in Figure 6 below and on the following page. The risks recurring across several sectors are highlighted below in no particular order. As mentioned, with environmental and social risk data there are inconsistencies and gaps in the data that is publicly available, potentially leading to incomplete findings or the understatement of environmental and social risks. This highlights the need to focus on enhancing data availability and quality.

In terms of ESG risks, along with data quality, it is imperative to highlight various mining operations can vary significantly in their impacts related to ESG matters.[48] See case study on page 21 for an example of a positive mining operation.

Risk type	Risk description
Biodiversity	Mining activity can have adverse effects on the natural habitats surrounding or influenced by a mine site, including the loss and destruction of wildlife, plants, and other organisms. This not only leads to the decline of biodiversity in places such as Indonesia, where the rise in nickel mining has led to significant biodiversity loss, but the erosion of natural capital too.[50] This represents a significant risk to industry, with more than half of global GDP either moderately or highly dependent on the natural environment.[51]
Child labour	In countries where mining operations are not properly regulated, or artisanal mining is widespread, the use of child labour can ensue. This undermines the basic rights of children, exposing them to hazardous working conditions and potentially leading to both fatal and non-fatal injuries.[52] This is most clearly documented in the Democratic Republic of Congo's (DRC's) cobalt mines, where it is estimated that some 40,000 children work in small-scale mining.[53] For downstream buyers, this involvement of child labour represents legal, operational, and reputational risks,[54] which can result in a wide range of challenges. However, abandoning CRM suppliers that are complicit in the use of informal labour may worsen existing poverty,[55] and as such, this risk is best managed through upstream collaboration with mine operators and civil society, and traceability as seen by the Fair Cobalt Alliance.[56] The Fair Cobalt Alliance offers actors across the cobalt supply chain a pre-competitive environment for collaboration to help strengthen and professionalise DRC's artisanal cobalt mining sector and contribute to local economic development at large.[57]
Forced labour	Instances of forced labour in CRM supply chains have been documented in mining and processing operations across certain countries for specific materials. These instances represent an infringement of human rights and present a significant risk for UK industry, primarily through the Modern Slavery Act. In the extraction stage, one example is the forced labour documented in Myanmar's rare earth element (REE) mines,[58] which China relied on for 38% of its REE imports in the first half of 2023.[59] In the processing stage, the use of forced labour is reportedly widespread within polysilicon production in Xinjiang, China, which accounts for around 35% of global supply.[60] As demand for these CRMs increases, UK industry will need effective due diligence of suppliers to avoid complicity in forced labour.
Water depletion	Mining and processing are a highly water intensive activities: processes including mineral extraction; dust suppression; and slurry transport all require large volumes of water.[61] While the water consumption of the mining sector is far less than some others, including agriculture, it still represents significant risk in the extraction of CRMs, with many mining regions located in water-scarce geographies experiencing heightened competition for limited resource, such as the Atacama region of Chile.[62] This has led to operational disruption in global mining locations[63] and could lead to greater challenges in the extraction of CRMs in the future.
Greenhouse Gas emissions	The mining and processing of CRMs can produce varying amounts of greenhouse gas (GHG) emissions. These emissions vary significantly based on the energy type used to power production processes,[64] including mining, milling, smelting, and refining. For example, nickel production can release 12-78 tonnes of GHG per tonne of refined metal based on the energy type used,[65] demonstrating a significant variance between suppliers. This represents a key risk for industry, as it works to reduce scope 3 emissions while establishing new and complex supply chains. GHG emissions of CRMs also vary significantly based on whether they are virgin or recycled materials. For example, recycled platinum is at least 95% less carbon intensive than virgin platinum,[66] demonstrating an environmental benefit of closed-loop supply chains.

[48] IRENA, "Geopolitics of the energy transition: Critical materials," International Renewable Energy Agency, 2023.
[49] Mercedes Ruhel, "Nickel miners linked to devastation of Indonesian forests," Financial Times, October 8 2023.
[50] Natural capital can be defined as the world's stocks of natural assets which include geology, soil, air, water and all living things.
[51] Amanda Russo, "Half of the World's GDP Moderately or Highly Dependent on Nature, Says New Report," World Economic Forum, January 19, 2020.
[52] International Labour Organization. "Hazardous Child Labour," International Labour Organization, Accessed October-November 2023.
[53] Michele Fabiola Lawson, "The DRC Mining Industry: Child Labor and Formalization of Small-Scale Mining," Wilson Center, September 1, 2021.
[54] Business & Human Rights Navigator, "Child Labour," United Nations Global Compact, Accessed October-November 2023.
[55] Task & Finish Group Member Interview, October - November 2023.
[56] Fair Cobalt Alliance, "Fair Cobalt Alliance," Accessed October-November, 2023.
[57] ibid.
[58] Kimberly Rogovin, "Internal Labour Migration in Myanmar," International Labour Organization, 2015.
[59] Reuters, "Myanmar rare earth mines still awaiting notice to restart - sources," Reuters, September 15, 2015.
[60] Alan Crawford and Laura Murphy, "Over-exposed: Uyghur Region Exposure Assessment for Solar Industry Sourcing", November, 2023.
[61] Schalk Burger, "Water-mining interdependence poses operational challenges, risks to miners", August 11, 2023.
[62] Nadja Kunz, "Towards a broadened view of water security in mining regions,", April 26, 2020.
[63] MIT Climate, "How much CO2 is emitted by manufacturing batteries?,", July 15, 2022.
[65] International Finance Corporation, "Net Zero Roadmap 2050 for Copper & Nickel Mining Value Chains,", Accessed October-November 2023.
[66] Task & Finish Group Member Interview, October – November, 2023.

Risk type	Risk description
Land degradation	The large volumes of mine tailings and discharge waters can have a range of adverse effects on the environment surrounding a mine, including land degradation. Toxic substances exposed by mining operations can contaminate the land and other ecosystems,[67] leading to poor soil health and damage to agricultural production.[68] This can undermine a miner's social licence to operate, reducing output and disrupting supply chains.
Health and safety	While modern health and safety provisions have enhanced protections for workers in the mining sector, there remains a risk of fatality and injury in CRM supply chains. This is evidenced by data from the International Council on Mining and Metals (ICMM), whose members recorded a total of 33 fatalities and 7,126 injuries in 2022, compared to 90 fatalities and 13,895 injuries in 2012.[69] However, this data does not include fatalities and injuries sustained in Artisanal and Small-scale Mining (ASM), where workers in the extraction of certain CRMs are exposed to additional health and safety hazards, including poorly constructed mine pits, lack of Personal Protection Equipment (PPE), and use of hazardous materials.[70] The mining of CRMs can have potentially disproportionate impacts on indigenous communities in resource rich areas, and have historically been associated with human rights abuses, armed militias, land loss, and displacement. The lack of community consultation surrounding the Fénix nickel mine in Guatemala has resulted in significant environmental and social issues for indigenous communities and Maya Q'eqchi' fishermen, which has led to a reported violation of their land and resource rights.[72]

Figure 6: Cross-cutting sector ESG risk register

The Australian Scandium Project, a case-in-point for sustainable mining

Scandium is a critical mineral that is in increasing demand for modern technologies – aerospace, lasers, and electronics – due to its alloying and emerging high-tech properties.

Today in Quebec, Rio Tinto has a commercial scale plant producing high quality scandium. Their operation involves an innovative process which extracts high purity scandium oxide from the waste streams of the existing titanium dioxide production, without the need for any additional mining.

Utilising waste streams provides more minerals from a single resource and reflects the expectations of today's consumers to heed the call to live more thoughtfully and ethically to protect the long-term future of our planet. The scandium production in Quebec will make Rio Tinto one of the largest producers of scandium in the Western world. In just two years, Rio Tinto has gone from testing the extraction process in a laboratory to being able to supply about 20% of the global scandium market. Like many other critical minerals, the market for scandium has been characterised by significant concentration among a small number of producer countries.

Rio Tinto's 2023 acquisition of a high-grade scandium resource in New South Wales will, once operational, more than double its annual scandium production. The Australian Scandium Project is a high value and rare scandium asset, but a very small physical asset with a small environmental footprint. Rio Tinto is also combining scandium with its low carbon aluminium to produce an alloy that is stronger, more flexible, and more resistant to heat and corrosion than pure aluminium.

The Australian Scandium Project is emblematic of Rio Tinto's focus on technology, using existing infrastructure and waste streams to become a significant and reliable supplier of this critical mineral.

[67] SNL Metals & Mining Database, "Large-scale physical and chemical land disturbance", European Commission, 2017.
[68] ICMM, "Safety Performance: Benchmarking Progress of ICMM Company Members in 2022", July 13, 2003.
[69] Pact Group Holdings https://pactgroup.com/wp-content/uploads/2021/08/WorkplaceHealthSafety_V6-copy-1-1.pdf, August 2021
[70] Pact World, "Pact World," Accessed October-November, 2023.
[71] IRENA, "Geopolitics of the energy transition: Critical materials," International Renewable Energy Agency, 2023.
[72] Task & Finish Group Member Interview, October - November 2023.

Sector Risk Assessment: Aerospace and defence

Foreword

The UK aerospace and defence sector depends on CRMs such as REEs, cobalt, hafnium, molybdenum, nickel, rhenium, tantalum, and tungsten for advanced technologies and systems. These materials are essential for aerospace and defence's operational effectiveness, safety, and sustainability. Clearly, there are national security considerations for defence as well. However, the last year has seen more volatility in metal prices than ever, reflecting the wider supply chain challenges. The ramp up in aerospace production rates and the conflict in Ukraine will create new pinch points in the availability and affordability of CRMs.

We need a collaborative approach between government and industry, based on trust, transparency, adaptability, and traceability. We need to ensure access to reliable and diversified sources of CRMs and invest in innovation and circular economy solutions. The Task and Finish Group, which I have been pleased to sit on, has been an excellent first step. It has comprehensively analysed the situation, identified the gaps and risks, and proposed clear recommendations for action.

I hope that this report will be a valuable resource and a catalyst for further dialogue and cooperation among all stakeholders in the CRM supply chain.

Kevin Craven
Chief Executive of ADS Group

Introduction

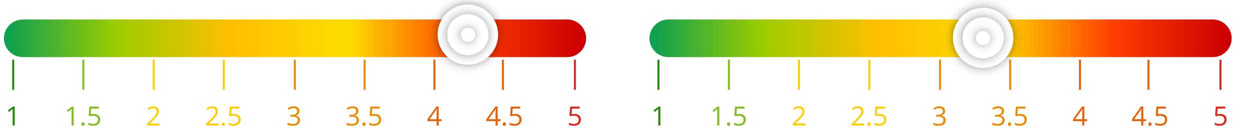
The UK aerospace and defence sector is large, sophisticated, and prosperous. In 2022, it had a combined turnover of £41 billion, with £20 billion in exports.[73] The aerospace and defence sector requires a variety of specialist materials and custom-made components derived from CRMs to manufacture products that meet strict specifications and can withstand harsh operational environments – alloys are particularly important. As a result, CRM supply chains span beyond the procurement of critical minerals and metals and are linked more closely to the supply of materials and components further down the value chain. As the aerospace industry recovers and returns to pre-Covid-19 levels, demand for these materials and components is expected to increase for applications such as jet engines and the requirements of future technologies.

Risk framework findings

This report uses a quantitative risk matrix to highlight the CRMs which pose the greatest risk to each industry (see methodology section). The chart below summarises the top ten CRMs for the aerospace and defence sector by overall supply risk (compound supply risk). The compound supply risk is comprised of two scores: 1) material importance (the impact of a disruption in supply on the industry), which was determined by stakeholder inputs; and 2) supply risk (the likelihood of a disruption given the material specific risk factors), which was derived from secondary data sources in the risk assessment. These two scores were multiplied to reach the compound risk score shown in Figure 7. In addition, the below table shows the environmental and social risk associated with each CRM and demonstrates the impact the material has on the environment and society.

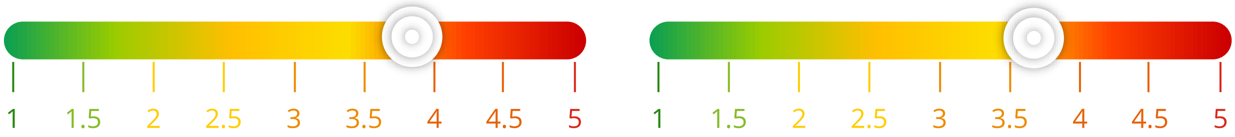
Compound supply risk | **Environmental and social risk**

Cobalt

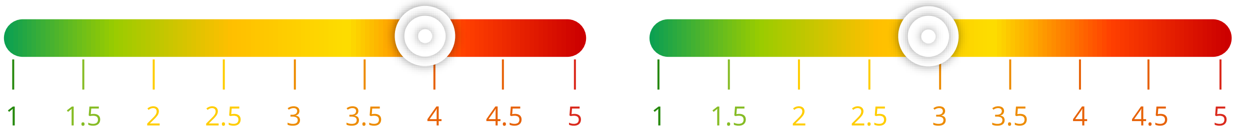


Beyond the environmental and social risks identified by the risk assessment, such as child labour, cobalt mining is also linked to eutrophication, ecotoxicity and human toxicity, which are not reflected in the score.[74]

Nickel



REEs



Limitations in data availability mean that the true supply risk and environmental and social risk presented by REEs are not reflected in the chart. For example, mine tailings produced during the extraction of REEs contain radioactive elements: thorium and uranium. These elements can cause significant damage to surrounding areas if they enter the environment through air, wastewater and rain leaching.[75]

[73] ADS, "Industry Facts and Figures," accessed October-November, 2023.
[74] Shahjadi Farjana, Namzul Huda & M.A. Mahmud, "Life cycle assessment of cobalt extraction process," Journal of Sustainable Mining, August 2019
[75] Petra Zapp et al., "Environmental impacts of rare earth production," MRS Bulletin, March 17, 2022.

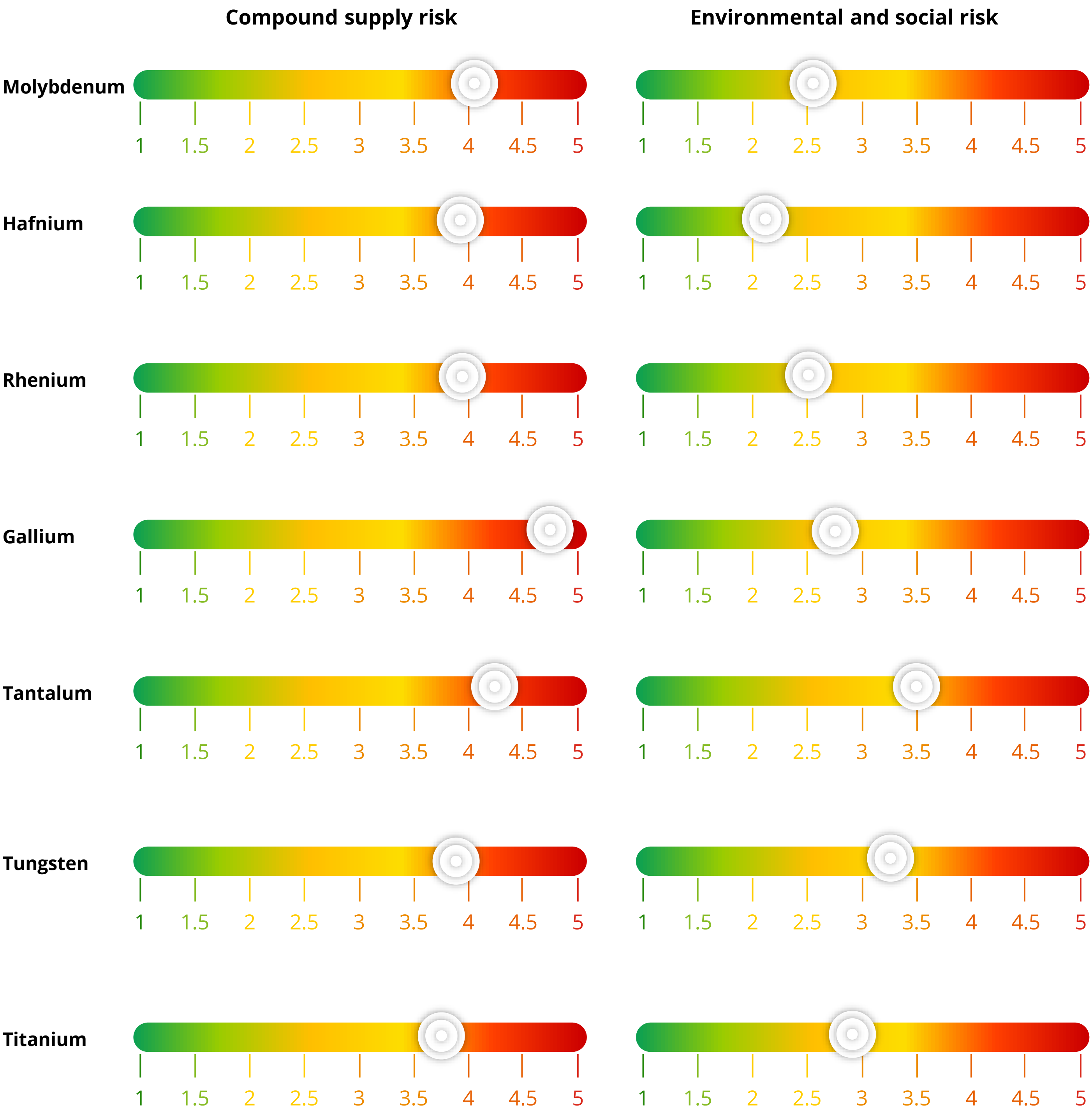


Figure 7: Aerospace and defence sector dependencies

> Beyond the minerals and metals shown in Figure 7, the aerospace and defence sector highlighted dependencies on beryllium, zirconium, platinum, lithium, vanadium, copper and silicon for various technologies and applications. These CRMs also had a high compound supply risk score based on the findings of the risk assessment but did not score as highly as those in Figure 7.

Risk register

The risk register below outlines the top three supply risks to the aerospace and defence sector based on analysis of quantitative and qualitative data, including the risk assessment and T&F Group member interviews. It is important to note that the risk register selected risks based on the highest score derived from the supply risk aspect of the methodology framework. ESG risks were evaluated per mineral, not per sector, hence their exclusion from the risk register and inclusion in the earlier section. For further information on ESG risks, please refer to the environmental and social risk section on page 20.

Risk type	CRMs impacted	Risk description
High import reliance	cobalt, nickel, REEs, molybdenum, hafnium, gallium, tantalum, titanium, tungsten	The aerospace and defence sector is heavily reliant on imported CRMs, including those highlighted in Figure 7. Disruption to the supply of these CRMs could have significant consequences for the UK, both in terms of economic and national security. This is especially true for CRMs where the UK is reliant on imports from hostile states. For example, titanium supply chains have faced challenges since early 2022 due to Russia's invasion of Ukraine and the industry dependence on a Russian supplier: VSMPO-Avisma. VSMPO-Avisma is the world's largest vertically integrated supplier of titanium and titanium alloy products and produces more than 45% of the world's aerospace titanium parts.[76] This has created significant challenges in the procurement of titanium across the UK's aerospace and defence sector and there remains a high dependence on these Russian imports despite efforts to diversify supply chains.[77] Hafnium imports from China are another potential risk area, as export licences are required due to its potential use in nuclear applications. There is a possibility that the Chinese Government could rescind these licences without warning, causing major challenges for the UK.[78] This risk also ties in closely with geopolitical tensions and diplomatic relations.
High processing concentration	cobalt, REEs, hafnium, rhenium, gallium, tungsten	A high processing concentration for CRMs poses a significant risk to global supply chains, as any disruption to processing activity could lead to shortages in the availability of processed resources. Considering the strict specifications of products used in the aerospace and defence sector, this could impact production of key components if OEMs are unable to obtain the required inputs. For example, aerospace manufacturers rely on cobalt for superalloys used in jet engines, 60% of which is processed in China.[80] If supplier OEMs are unable to procure the specification of cobalt required, this could interrupt manufacturing.
Companion metal fraction	cobalt, hafnium, gallium, rhenium	A high dependence on CRMs mined as companion metals can create supply constraints if demand increases. The aerospace and defence sector has a high dependence on a number of these CRMs. For example, gallium is obtained primarily as a by-product of aluminium production,[81] while rhenium is extracted as a secondary product of copper mining.[82] As demand increases for these CRMs, both from the aerospace and defence sector and wider industry, this could create a risk of shortages in the future.

The UK has no domestic primary sources of defence CRMs; outside of recycled material. Currently everything must be imported.[79]

Figure 8: Aerospace and defence supply risk register

[76] European Commission, "Titanium metal: Impact assessment for supply security," European Union, 2022.
[77] Task & Finish Group Member Interview, October – November, 2023
[78] Task & Finish Group Workshop, October - November 2023
[79] Task & Finish Group Member Interview, October – November 2023
[80] Song et al., "China Factor: Exploring the Byproduct and Host Metal Dynamics for Gallium-Aluminum in a Global Green Transition," Environmental Science & Technology, Feb 15, 2022.
[81] ibid.
[82] Paul Lusty et al., "UK criticality assessment of technology critical minerals and metals," British Geological Survey, June 30, 2022.

Key findings

Highly specialised materials limit substitutability and inhibit recycling

A key challenge facing the aerospace and defence sector is the high specification of input materials and strict sourcing requirements from qualified suppliers.[83] The current level of specificity often leads downstream manufacturers to focus primarily on the qualities of a CRM or derived component at the expense of diversifying their supply base. This can leave prime manufacturers vulnerable to supply chain disruption while preventing OEMs and small medium enterprises (SME) suppliers from pursuing their dual sourcing strategies without incurring the costs of product recertification.[84] While it is essential to maintain the high standards of input materials and components, this level of specification has historically impeded the sector's ability to build resilience in CRM supply chains. Further, it can make it much more difficult to recycle complex alloys. This means that valuable CRMs are lost during downcycling and dependence on virgin CRMs – while their associated GHG emissions and biodiversity loss – remains high. In response to these challenges, ADS recommended the Government and Ministry of Defence explore how to introduce greater flexibility in technical and design specifications to allow for substitution, minimising risk exposure.[85]

Superalloys require minor metals whose supply is dependent on the extraction of other primary metals

Minor metals – those traditionally not traded on formal exchanges and produced in relatively low volumes as companion metals[86] – are required by the aerospace and defence sector to produce superalloys. These specialist alloys are selected for their unique properties, such as heat and corrosion resistance, which allow them to maintain a high performance in demanding environments.[87] Superalloys typically have nickel, iron, or cobalt as their base, with quantities of other alloying elements, such as hafnium, added as coatings or additives to provide specific properties.[88] The UK depends heavily on imports from the US, China, Japan, and several European countries for its primary supply of alloying metals. As companion metals, the production of many of these minor metals is dependent on the extraction of other primary metals, which makes the supply less responsive to increased demand. As a result, if demand for primary metals does not increase in other sectors, the availability of minor metals for aerospace and defence could become more limited.[89] To an extent, this means that the aerospace and defence sector is dependent on primary metal demand from other sectors, including those not covered by this report. This is a major challenge for the industry, and there is a need to take a full value chain view to better understand these dependencies and how they will affect future material supplies.

[83] Task & Finish Group Workshop, October - November 2023
[84] ibid.
[85] Task & Finish Group Member Interview, October - November 2023.
[86] Minor metals trade association, "Glossary of Minor Metal Terms", Accessed October-November 2023.
[87] Andrew Mouritz, "Introduction to aerospace materials," Woodhead Publishing, 2012
[88] Art Kracke, "SUPERALLOYS, THE MOST SUCCESSFUL ALLOY SYSTEM OF MODERN TIMES - PAST, PRESENT AND FUTURE" The minerals, metals & materials society, 2010
[89] Narendra Singh, Paul Lusty and Pierre Josso, "Scoping Study on metals used in specialist alloys in the aerospace industry," British Geological Survey, 2023

The UK's supply chain is primarily reliant on semi-finished materials and components, limiting visibility of CRM supply risks beyond tier 1

The aerospace and defence sector's prime manufacturers in the UK rely heavily on finished or semi-finished materials and components. These products are manufactured through a complex supply chain of SMEs, who may not have the same level of understanding of supply chain risks as prime manufacturers.[90] As a result, visibility of the commodity stage of supply chains is weak, making it difficult to identify pinch points that could disrupt downstream procurement of materials and components.[91] This lack of visibility means that supply risks may not be identified or mitigated appropriately.

Moreover, the sector's limited upstream visibility may mean that there is little oversight of environmental and social risks. Based on the initial findings of the risk assessment, this lack of oversight may impact manufacturers' ability to address impacts including biodiversity loss caused by inputs such as nickel, REEs, and titanium. Better supply chain traceability in the most high-risk value chains could go some way to better understanding and eventually mitigating these risks.

UK industry is reliant on few jurisdictions to provide CRMs needed to produce advanced technologies

There are a range of advanced technologies that are critical to the production of aerospace and defence products. These include electronic sensors, guidance and radar systems, and communication devices, which are manufactured using high-risk CRMs such as REEs and gallium.[92] China exercises significant control over these supply chains; producing 90% of processed REEs[93] and 94% of processed gallium;[94] and has shown its willingness to apply trade restrictions to both these CRMs at times when geopolitical tensions rise, most recently for gallium in August 2023.[95] Such restrictions present a challenge to the aerospace and defence sector due to its vital role in national security. This leaves companies more exposed to geopolitical issues with limited options for diversification.

Focus on rhenium recycling

Rhenium is a key element used to create the nickel-based superalloys in rocket and aircraft engines. Its strength and heat resistance allow engines to maintain a higher temperature during flight, which increases efficiency and reduces fuel consumption.[96]

Between 2006-2008, rhenium prices increased significantly, rising to approximately $12,000 per kilogram at their peak.[97] This rise was driven primarily by the combined demand for aerospace and industrial gas turbines, but was also because of the tight supply chains as a rare companion metal. In response to this price increase, a rhenium recycling industry was created.

Rhenium price history chart[98]

Rhenium was recovered from nickel superalloys where previously it would have been lost, and OEMs worked with recyclers to collect material from scrapped and end-of-life blades, amongst other sources.[99] Over time, the increased supply from recovered sources has helped prices to fall significantly and demonstrates the benefits of closed-loop supply chains for building domestic resilience and limiting price volatility.

[90] Task & Finish Group Workshop, October - November 2023.
[91] ibid.
[92] ibid.
[93] Philip Andrews-Speed & Anders Hove, "China's rare earths dominance and policy responses," Oxford Institute for Energy Studies, June 2023.
[94] Publications office of the European Union, "Study on the critical raw materials for the EU 2023," European Commission, 2023.
[95] Catherine Evans, "Companies respond to China's curbs on gallium and germanium exports," Reuters, July 7 2023.
[96] Narendra Singh, Paul Lusty and Pierre Josso, "Scoping Study on metals used in specialist alloys in the aerospace industry," British Geological Survey, 2023
[97] Paul McGuiness and Romana Ogrin, "Securing Technology Critical Metals for Britain," University of Birmingham, Accessed October-November, 2023.
[98] ibid.
[99] ibid.

Sector Risk Assessment: Automotive

Foreword

The global automotive industry is undergoing a fundamental technological change, decarbonising products and processes whilst seeking to sustain mobility for all. The transition is altering dependencies, requiring the sourcing of new products, components, and raw materials. The sector has always had demand for certain CRMs – notably aluminium, copper and PGMs – but added to this are increasing requirements for CRMs such as lithium, nickel, cobalt and graphite for battery production, rare earth elements for permanent magnets in electric motors, platinum for other next generation power units such as fuel cells, rhodium in catalytic converters and ruthenium in mirror coatings. Securing reliable, affordable, and sustainable supplies of these CRMs is essential for the long-term future of the industry.

The UK automotive sector is export-led and diverse, from super car manufacture to trucks, buses, and taxis. The specific needs of each segment must be reflected, minimising risk and maximising flexibility and resilience with a recognition that overseas markets will affect technological decision-making. The minerals required are, by definition, often scarce and in high demand so any supply strategy must be complemented by the prioritisation of the four Rs of sustainability and circularity: reuse, repair, remanufacture and recycle, to maximise the value derived from every gramme sourced.

With conventional, fossil fuelled, vehicle production largely being phased out this decade, a strategy that secures supply of CRMs – and aligns to battery, supply chain and broader industrial strategies - will help position the UK as an attractive destination for automotive investment in a fiercely competitive global environment.

Mike Hawes
Chief Executive of The Society of Motor Manufacturers and Traders (SMMT)

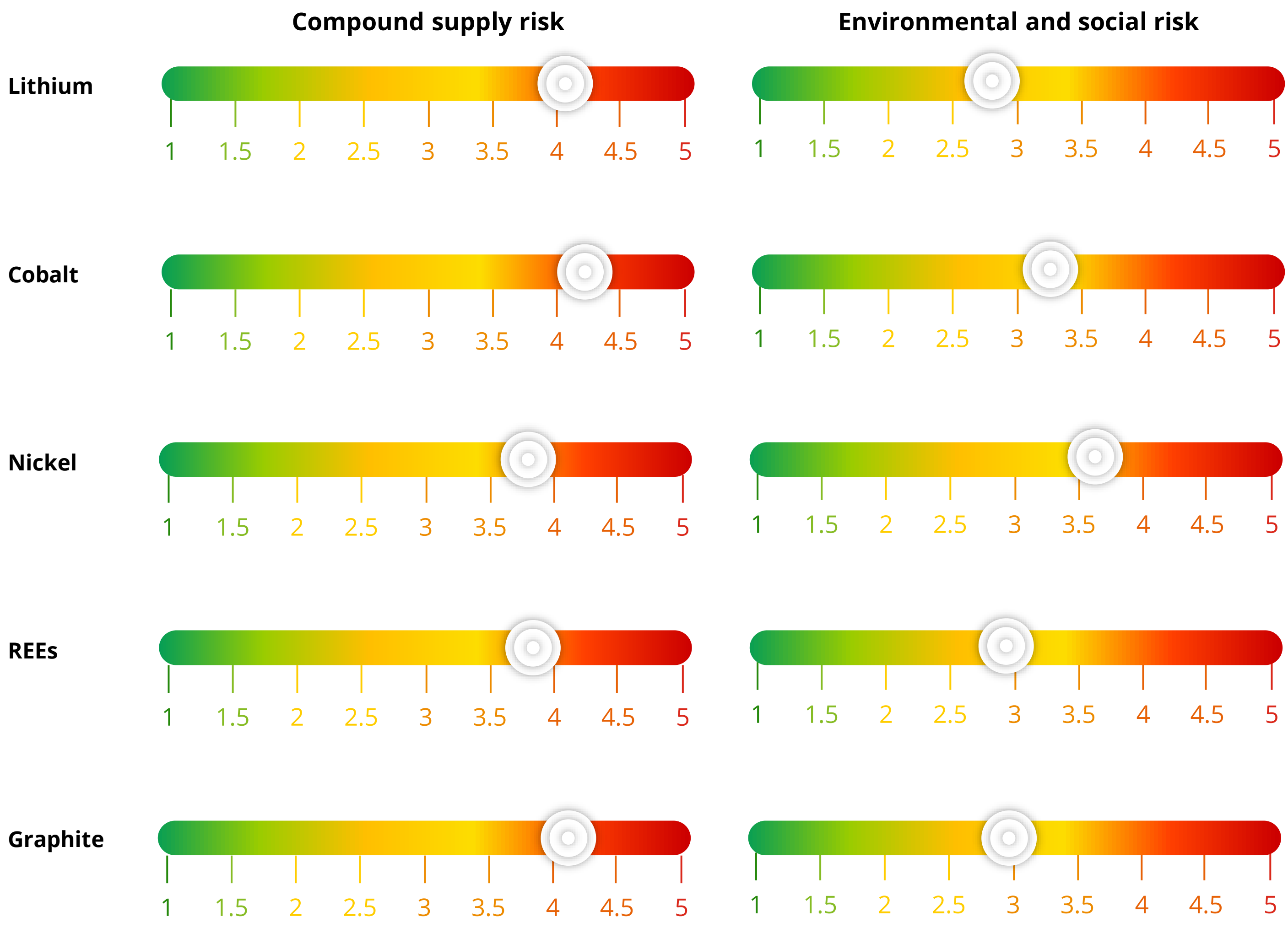
Introduction

UK Government policy mandates that all new light-duty and heavy-duty vehicle sales must be electric vehicles (EVs) or zero emission vehicles (ZEVs) by 2035 and 2040 respectively, as the sale of internal combustion engine (ICE) vehicles is phased out. This sector transformation presents a range of risks that must be overcome to successfully shift towards low carbon vehicles, while maintaining the competitiveness of UK manufacturing. Among these is the continuous and sustainable supply of CRMs; especially those used in batteries, electric motors, and hydrogen fuel cells (HFCs).

According to SMMT, the automotive sector contributes £67 billion turnover and £14 billion value added to the UK economy, employing 780,000 directly and indirectly, and accounting for 10% of total UK exports.[100] To maintain this contribution, the automotive sector must establish resilient CRM supply chains to support the production of low-carbon vehicles and continue to attract the next generation of manufacturing to UK shores.

Risk framework findings

This report uses a quantitative risk matrix to highlight the CRMs which pose the greatest risk to each industry (see Appendix 2 and 3). Figure 9 summarises the top ten CRMs for the automotive sector by overall supply risk (compound supply risk). The compound supply risk comprises two scores: 1) material importance (the impact of a disruption in supply on the industry), which was determined by stakeholder inputs; and 2) supply risk (the likelihood of a disruption given the material specific risk factors), which was derived from secondary data sources in the risk assessment. These two scores were multiplied to reach the compound risk score shown in Figure 9 below. In addition, the below table shows the environmental and social risk associated with each CRM and demonstrates the impact the material has on the environment and society.



[100] Society of Motor and Manufacturers and Traders, "SMMT Motor Industry Facts 2023," May, 2023.

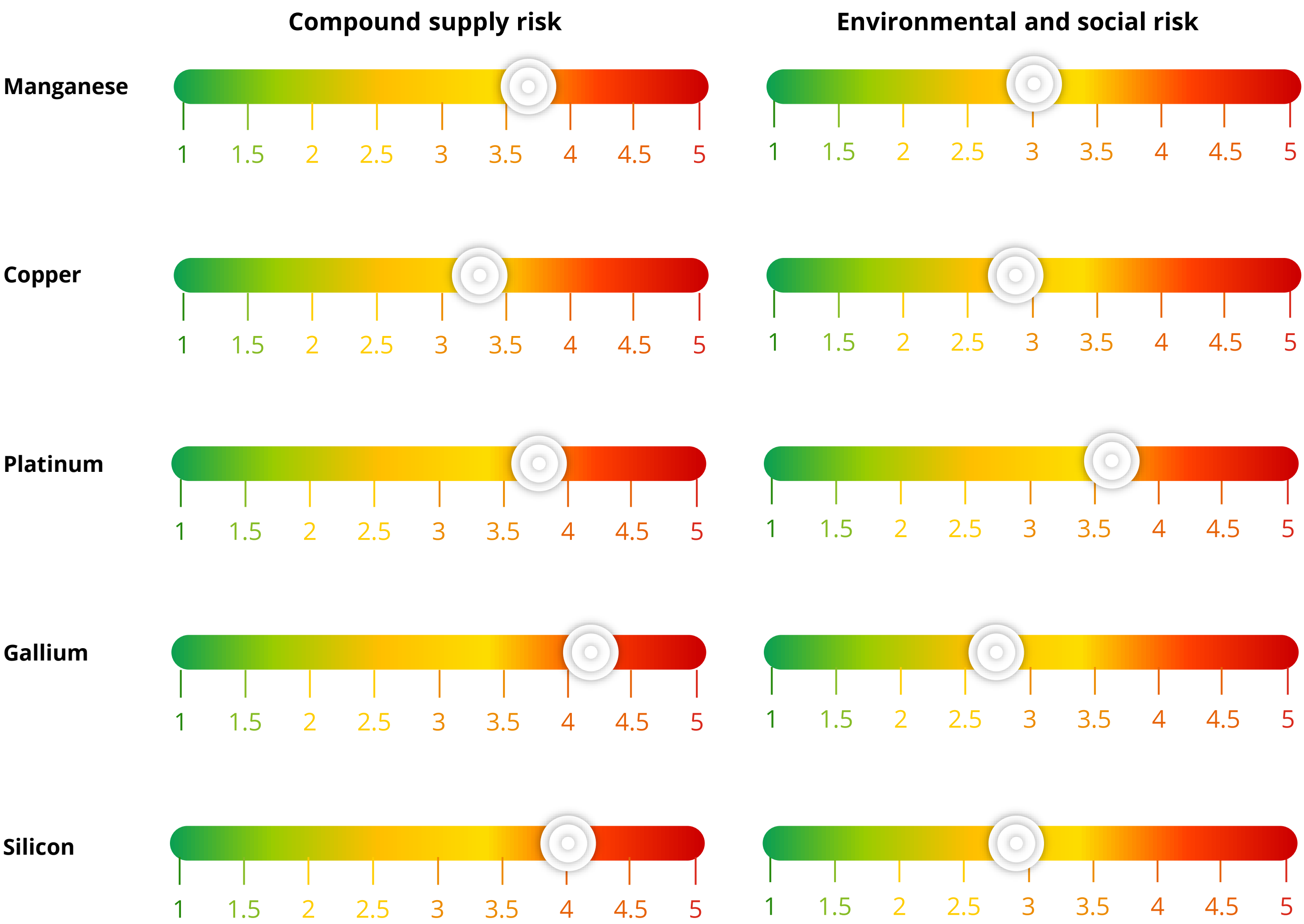


Figure 9: Automotive sector dependencies

Beyond the minerals and metals shown in Figure 9, the automotive sector highlighted dependencies on aluminium, boron, iridium, niobium, palladium, phosphates, rhenium (including in the form of ammonium perrhenate), rhodium, ruthenium, silicon, tantalum and titanium for various technologies and applications.

> Graphite is a key battery material used in the anode of a cell. There are two forms of graphite, derived from mineral sources (natural) or from calcined petroleum coke (synthetic). In the production of synthetic graphite, the coke must be heated to 3000 degrees Celsius in the open for up to 10 days, producing 300-500kg of carbon per tonne, up to four times more than natural graphite. The UK has an opportunity to create sustainable synthetic graphite that uses a closed system with carbon capture, utilisation and storage (CCUS) to capture the CO_2.[101]

Risk register

The risk register below outlines the top three supply risks to the automotive sector based on analysis of quantitative and qualitative data, including the risk assessment and T&F Group member interviews. It is important to note that the risk register selected risks based on the highest score derived from the supply risk aspect of the methodology framework. ESG risks were evaluated per mineral, not per sector, hence their exclusion from the risk register and inclusion in the earlier section. For further information on ESG risks, please refer to the environmental and social risk section on page 20.

[101] Benchmark Source, "ESG of graphite: how do synthetic graphite and natural graphite compare?," November 24, 2022.

Risk type	CRMs impacted	Risk description
High price volatility	lithium, cobalt, nickel, REEs	Price volatility in CRMs markets can create cost challenges for automotive manufacturers as they seek to transition towards EVs. These high costs, primarily a result of surging demand for lithium, nickel, and cobalt, have created challenges around the affordability of EVs compared to ICE vehicles[102] as the UK Government looks to increase uptake. These issues could be compounded by any severe price volatility, such as that seen in nickel markets during March 2022 when the LME stopped the trading of nickel.[103] Similarly, lithium, a key battery metal, went from a price of close to $10,000 per tonne in early 2021 to $80,000 in early 2023, before dropping to around $15,000 at the end of 2023.[104]
High mining concentration	lithium, cobalt, REEs, graphite, nickel, manganese, silicon	Disruption to mining activity in supply chains with a high mining concentration could lead to sustained supply-side shortages for a range of components across the UK's automotive sector. Mining concentration can also be considered a risk when the control of mining assets lies with a single or few parties. When assessing risks around access to materials it is important to consider not only the country where the mine is located, but also the country that controls the mine (and therefore controls contracts and offtake agreements). For example, almost 70% of the world's REEs are mined in China[105], although this is declining as key mining provinces have started to baulk at the high human and environmental cost of heavy REE mining (which has implications for the water table and general health). Indeed, Chinese-owned firms are increasingly operating mines in other regions, such as Myanmar (see boxed test), before exporting them to China.[106] Any decline in mining activity could impact permanent magnet availability and harm electric motor production.
Weak national governance in supplier countries	cobalt, graphite, manganese, platinum, nickel, silicon	Instability caused by weak national governance can create continuity of supply challenges for automotive manufacturers. The lack of effective policies and well-governed institutions in supplier countries can inhibit effective scale up and stability of supply. For example, 63% of the world's cobalt is mined in the DRC[107] – a country which consistently scores poorly in the World Bank's Worldwide Governance Indicators. The OECD report 'How to address bribery and corruption risks in mineral supply chains' highlights the potential risks associated with weak national governance, including discretionary bid evaluation or mining rights allocation processes; inappropriate use of force, solicitation, and extortion by security forces for the illegal extraction and trade of minerals; and/or inefficient taxation and other government fees.[108] While platinum (and other PGMs) are often classified quantitatively as a material that may be impacted by weak national governance in supplier countries, their supply chains have been remarkably sustainable thus far.[109]

Figure 10: Automotive supply risk register

[102] Ben Jones, Robert Elliott, Viet Nguyen-Tien, "The EV revolution: the road ahead for critical raw materials demand," Applied Energy, December 15, 2020.
[103] Eric Onstad, "LME forced to halt nickel trading, cancel deals, after prices top $100,000," March 8, 2022.
[104] Daily Metal Prices, "Lithium Prices for the Last Year," Accessed October-November, 2023.
[105] U.S. Geological Survey, "Mineral Commodity Summaries 2023," U.S. Geological Survey, January 31, 2023
[106] Global Witness, "Myanmar's poisoned mountains," August 9, 2022
[107] Publications office of the European Union, "Study on the critical raw materials for the EU 2023," European Commission, 2023
[108] OECD, " Frequently Asked Questions: How to address bribery and corruption risks ," OECD, 2021.
[109] Task & Finish Group Workshop, October – November, 2023.

Key findings

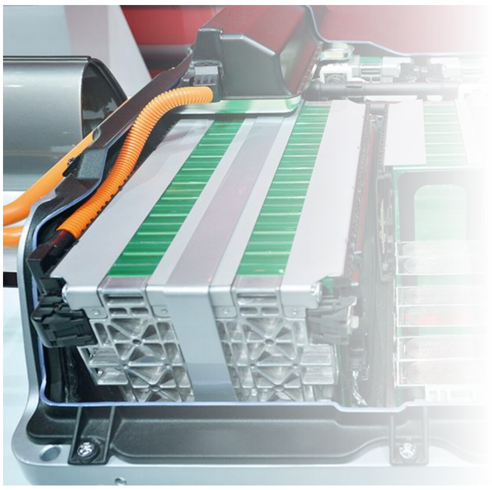
Evolving battery chemistry with no single global approach leaves future CRM demand unknown

EV battery chemistries are constantly evolving as researchers look to boost energy density and utilise alternative materials. There are a range of chemistries available and in development with varying properties. In the UK, EV batteries are predominantly lithium nickel manganese cobalt oxide (NMC),[110] rather than lithium iron phosphate (LFP) batteries (another established battery chemistry).[111] Researchers are exploring eliminating cobalt entirely through high nickel cathodes[112] which could help alleviate the automotive sector's future dependency on cobalt. This has the potential to allow for recycled cobalt coming out of today's cobalt-rich batteries to satisfy a greater proportion of demand, although the current forecasted demand for cobalt means that the UK automotive sector will be reliant on virgin resources for the foreseeable future. Even considering these developments, the UK automotive sector is most likely to continue to depend on nickel-rich chemistries given its premium and performance orientation.[113] On the anode side, silicon doping is being looked at as a means for increasing energy density and improving battery performance,[114] which may relieve pressure on graphite, but also could potentially lead to an increased dependency on silicon in the future. Evolving battery chemistry will significantly affect the sector's dependency on specific CRMs; nevertheless, CRMs – in varying quantities and with different risks and dependencies – will continue to be a concern as the EV sector grows in the UK.

Green Alliance published a report noting that demand reduction is also a key strategy to deal with the demand for battery metals. It notes that "If the UK were to bear down on battery sizes so that half of its EV sales had smaller batteries of around 30kWh capacity (approximately 25% lower than the current average battery size), the UK's consumption of CRMs for EV batteries could fall by 61% per year compared to the high SUV scenario".[115]

Use of REEs in EVs are needed for key design elements with limited upstream supply diversification

Modern EVs have a high dependence on REEs, most notably the permanent magnets used in electric motors. These permanent magnets are primarily produced in China from REEs processed in the country, largely neodymium, but also dysprosium and terbium.[116] This means there is limited opportunity for manufacturers to diversify supply for either permanent magnets or REEs as EV manufacturing is scaled. Recovery of REEs[117] is another challenge facing the automotive sector. Further, there is a risk that REEs used in small quantities elsewhere in an EV will be difficult to recover and recycle due to vehicle design.[118] Developments in recycling technologies will be needed to maximise the viability of secondary sourcing in the UK going forward. Business model innovation will also be key to ensuring that separated REE containing components are collected at scale in order to provide the feedstock for recycling plants.



An emerging major mining source of REEs is Myanmar. As China has started to decrease its rare earth mining, Chinese companies have looked abroad to Myanmar as an alternative source, with many companies funding and controlling mining operations there. Many of these mines are in conflict affected areas with weak governance, dominated by local warlords. This is reportedly leading to a series of human and environmental sustainability issues including very poor health and safety standards and the reported polluting of the local water table.[119]

[110] Task & Finish Group Workshop, October - November 2023.
[111] Steffen Link, Christoph Neef and Tim Wicke, "Trends in Automotive Battery Cell Design: A Statistical Analysis of Empirical Data," March 8, 2023.
[112] Task & Finish Group Workshop, October - November 2023.
[113] ibid.
[114] Gina Roos, "Silicon Anodes Improve Li-on Batteries," EE Times Asia, June 12, 2023.
[115] Johann Beckford, "Big car, little car: the sustainability implications of growing vehicle sizes," Leadership for the Environment, November 8, 2023.
[116] Aclara, "Heavy rare earths," Accessed October-November 2023.
[117] James Billington, "UK company creates 'world's most sustainable electric vehicle motors,'" Advanced Electric Machines, April 1, 2021.
[118] Task & Finish Group Workshop, October - November 2023.
[119] Global Witness, "Myanmar's poisoned mountains," August 9, 2022.
Picture reference: https://news.mit.edu/2021/designing-better-batteries-electric-vehicles-0816

REE Recycling the case of Hypromag

The UK Hypromag REE Magnet Recycler project,[120] developed by researchers at the University of Birmingham, brings positive impacts to the UK's economy and environment. The UK is heavily reliant on imports of REEs, which are used in a wide range of high-tech applications. The most valuable are those in permanent magnets, which are composed of either neodymium iron boron or samarium cobalt. By developing a technology that recovers REEs from waste magnets, Hypromag could reduce the UK's dependence on imports and promote domestic production of REEs.

The Hypromag REE Magnet Recycler is a technology that recovers REEs from waste magnets, by exposing products to hydrogen at room temperature and atmospheric pressure, causing the neodymium iron boron magnets to break apart and generate demagnetised powder that is easier to extract. The nickel coating can be mechanically separated from the surface of the magnets, leaving behind a highly pure neodymium iron boron powder that can be reprocessed into magnetic materials or rare earth alloys.

The technology has several environmental and economic benefits. By recovering REEs from waste magnets, the need for mining new REEs is reduced, which helps to conserve natural resources and reduce the environmental impact of mining. The technology also promotes a circular economy by keeping valuable materials in use and reducing waste.

Hydrogen fuel cells (HFCs) may play a role in the electrification of car fleets with a greater focus on commercial vehicles

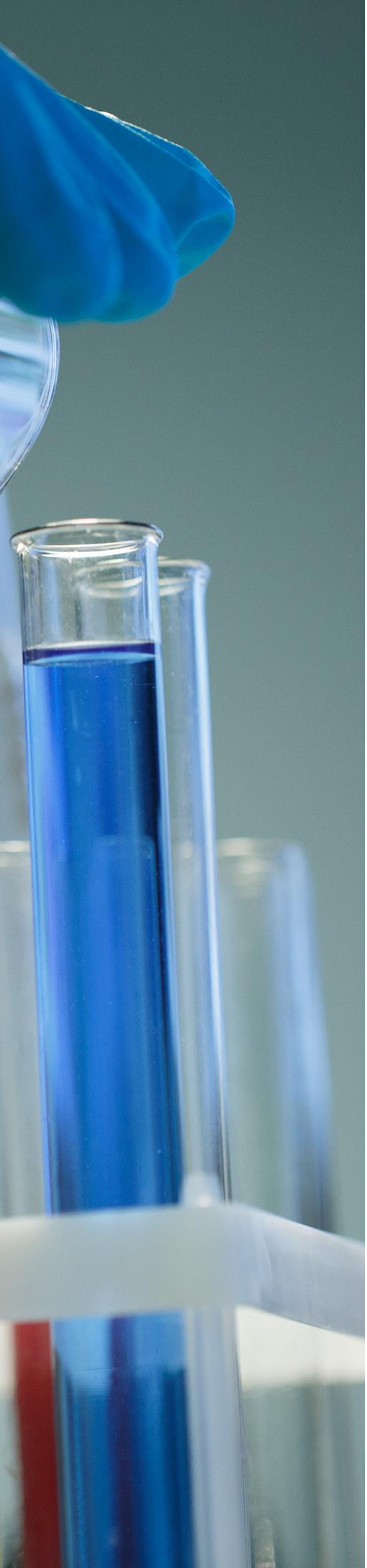
While at a much earlier stage of commercialisation than EVs, HFC vehicles are expected to play an active role in the UK's automotive sector once economies of scale are realised. In certain types of commercial vehicles, such as heavy goods vehicles (HGVs) and coaches, and in combination with certain usage/duty cycle cases (e.g. long distance, heavy load), battery EV technologies may not be seen as the optimal replacement for ICEs, primarily due to constraints in range, weight, recharging times, and payload capacity sacrifice in favour of heavy batteries.[121] HFC powered commercial vehicles offer a possible solution to this, with potential refilling times of 10-15 minutes for a HGV.[122] Production of HFCs is dependent on platinum as an effective and sufficiently durable catalyst for the anode and cathode reactions. At current loadings, platinum costs on a fuel cell passenger car are typically less than £700, while they are roughly £4000 in a typical fuel cell HGV. However, there is potential to reduce these loadings even further, seen through a process called thrifting, which seeks to reduce platinum content without sacrificing performance.[123] This is a standard approach in the PGM industry to ensure there are no availability constraints: thrifting has for decades been a feature of PGM-based ICE vehicle exhaust aftertreatment. Coupled with recycling, which is routine for ICE vehicle catalytic converters (and has already been accomplished for platinum in end-of-life HFC vehicle stacks), this will considerably mitigate any supply chain risks. However, continued supply of platinum from southern Africa will also be necessary. The main risk to this continued supply arises from concerns about future platinum demand as ICE vehicles are phased out. HFC vehicles will be replacement demand and will therefore provide crucial incentive for continued investment in platinum mining.[124]

Industry is increasingly dependent on copper for the vehicle electrification transition

The electrification of the UK's automotive sector will increase its copper dependency for two core uses: EV production and charging infrastructure. A typical EV requires 83kg of copper per vehicle, representing roughly a four-fold increase compared to an equivalent ICE vehicle.[125] The requirement for a fuel cell vehicle or hybrid EV is much lower. A battery truck contains over 400kg of copper (but again, fuel cell trucks have much lower copper requirements, typically less than 60kg). Meanwhile, a fast-charging point requires 8kg of copper,[126] without accounting for connectivity to the grid. This increased demand for copper is mirrored in other industries as part of the energy transition.[127] This means that the automotive sector will need to manage the increased competition, increase supply and explore greater use of recycled copper, to ensure continuity of supply for EVs.

> Copper is one of the easiest metals to recycle and can technically be recycled at a 100% efficiency. Current recycling capacity in the UK is limited and this could be scaled up significantly.[128]

[120] Hypromag, "Rare earth magnet recycling," Accessed October-November 2023.
[121] Task & Finish Group Workshop, October - November 2023.
[122] Xavier Bour, "Battery or hydrogen: What is the best solution to achieve zero emission trucking?," CEVA logistics, February 1, 2023.
[123] Interview with T&F Group member.
[124] Task & Finish Group Workshop, October - November 2023.
[125] Colin Bennett and Bryony Samuel, ""The Electric Vehicle Market and Copper Demand," International Copper Association, June 2017.
[126] ibid.
[127] IEA "The Role of Critical Minerals in Clean Energy Transitions," International Energy Agency, 2021.
[128] Task & Finish Group Workshop, October - November 2023.



Sector Risk Register: Chemicals

Foreword

With a reported 96% of all manufactured goods containing chemicals, industry supply chains are both broad and complex, with a dependency on a wide range of metals and minerals, including cobalt, nickel, manganese, graphite, platinum, palladium, and silicon. These CRMs, and others, are critical to the country's net zero transition – underpinning industrial catalysts such as electrolysers to produce green hydrogen and ammonia production – and are essential for applications with energy security implications, such as the processing of petrochemicals and industrial gases. As well as product dependencies on CRMs, the chemical industry is also reliant on certain key metals and minerals for the functioning of its operational asset base. The transfer of substances and products around chemical plants is dependent on pumps and pipework, the effectiveness of which requires nickel and other alloying materials. Copper, rhodium, nickel, and zinc are also critical inputs to plastic-based pipework.

The global and interdependent nature of chemical supply chains, does mean that the business models of chemical businesses increasingly reflect a secondary sourcing capability for CRMs, helping to reduce supply chain risk. However, the war in Ukraine and broader geo-political tensions pose significant threats to the resilience of UK chemical businesses and their wider customer base, so we very much welcome the work of the Task & Finish Group, its focus on risk, reliance and mitigation, and our sector's involvement in recommending actions to secure our collective long-term future.

Stephen Elliott
Chief Executive of Chemical Industries Association (CIA)

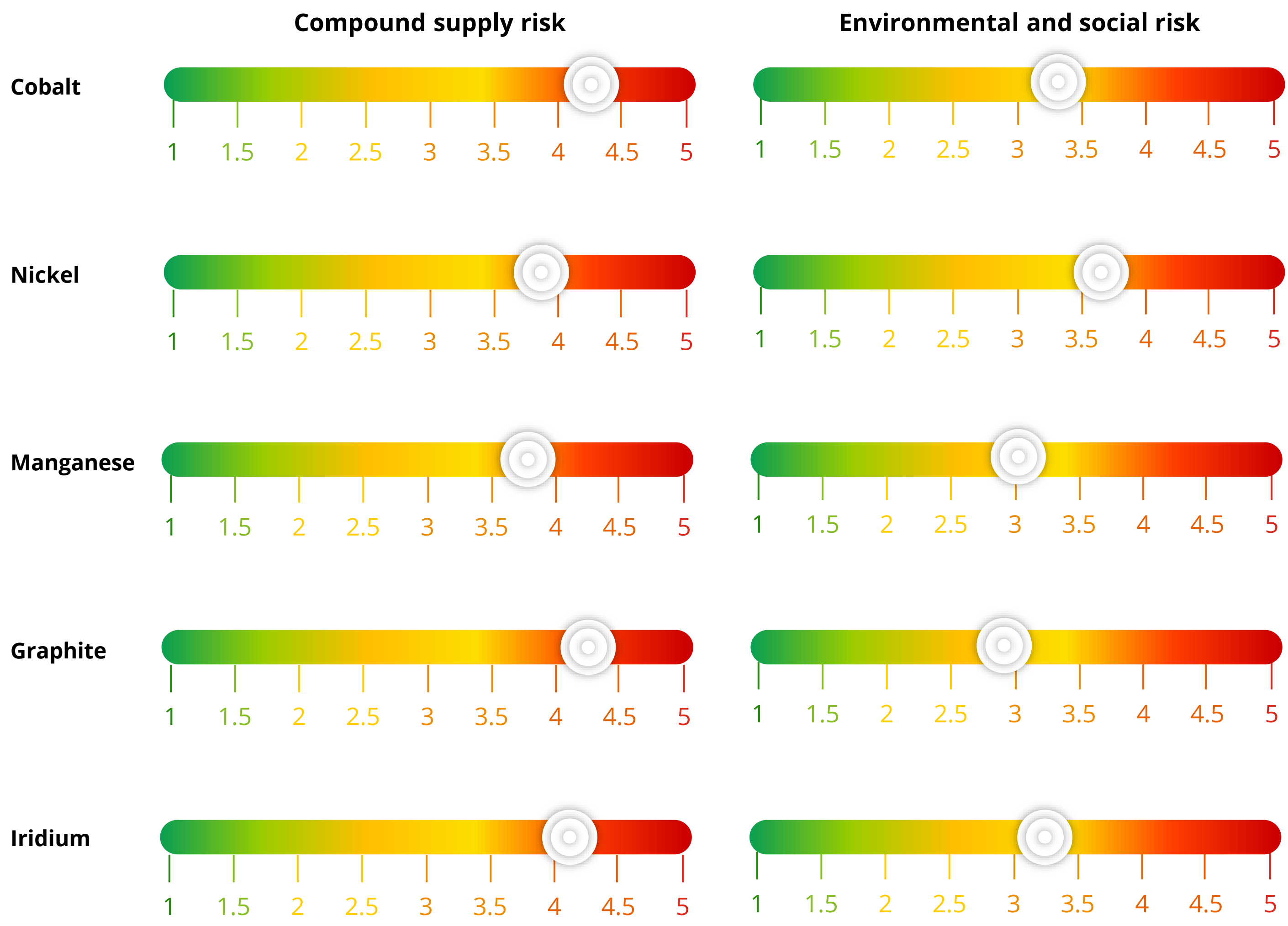
Introduction

The chemical industry plays a critical role in linking together a broad range of supply chains from providing energy and feedstocks (raw materials) to advanced materials, fine chemicals, life sciences and consumer products. The diverse nature of the chemicals sector means that mineral and metal dependencies are far broader than those of other industries, with almost all elements in the periodic table required in some capacity. The chemical industry provides critical materials and technologies for all the other sectors included in this report.

According to the CIA, the chemical industry is one of the largest sectors in the UK, adding almost £25 billion of value to the UK economy, with estimated sales of around £66.7 billion.[129]

Risk framework findings

This report uses a quantitative risk matrix to highlight the CRMs which pose the greatest risk to each industry (see methodology section). Figure 11 summarises the top ten CRMs for the chemicals sector by overall supply risk (compound supply risk). The supply risk is calculated by multiplying the impact of a disruption to supply (material importance) by the likelihood of a disruption to supply (supply risk). In addition, the below table shows the ESG risk associated with each CRM that demonstrates the impact the material has on the environment and society. The diverse nature of the chemicals sector means that mineral and metal dependencies are far broader than those mentioned below, with almost all elements in the periodic table required in some capacity. Given the complex nature of the chemical industry, there is a broad dependency on CRMs. Further, the complexity of supply chains and the application of the CRMs in processes makes it is challenging for the sector to identify CRM uses further upstream and downstream.



129 Tom Warren and Simon Marsh, "Our Industry." Accessed October-November 2023.

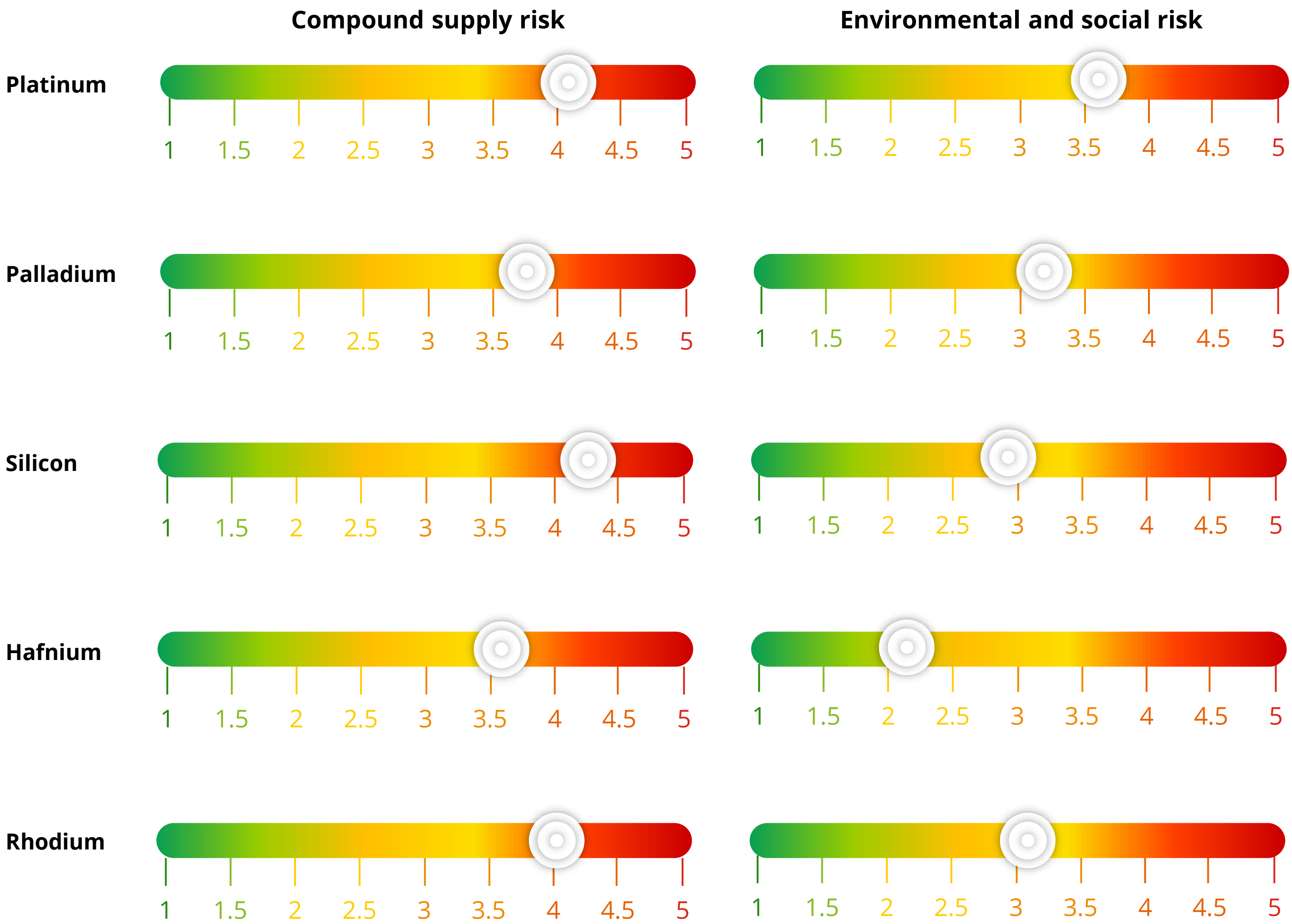


Figure 11: Chemicals sector dependencies

Beyond the minerals and metals shown in Figure 11, the chemical sector highlighted dependencies on aluminium, rhodium, ruthenium, and hafnium for various applications. These CRMs had a high compound supply risk score based on the findings of the risk assessment but did not score as highly as those in Figure 11.

40% of the global nickel reserves are in locations with high biodiversity and protected areas, and 35% in areas with high water stress. Indonesia and the Philippines are the most impacted regions from high or extreme exposure to biodiversity and water scarcity risks as a result of nickel laterites processing.[130]

[130] Niall Smith, "Nickel: A green energy necessity with grave environmental risks," Versik Maplecroft, July 29, 2018.

Risk register

The risk register below outlines the top three supply risks to the chemicals sector based on analysis of quantitative and qualitative data, including the risk assessment and T&F Group member interviews. It is important to note that the risk register selected risks based on the highest score derived from the supply risk aspect of the methodology framework. ESG risks were evaluated per mineral, not per sector, hence their exclusion from the risk register and inclusion in the earlier section. For further information on ESG risks, please refer to the environmental and social risk section on page 20.

Risk type	CRMs impacted	Risk description
High import reliance	cobalt, nickel, manganese, graphite, platinum, palladium, silicon, hafnium	The globalised, interdependent nature of chemicals supply chains means that material import reliance is common practice across the sector, with no one country able to rely on domestic suppliers alone.[131] As a result, the risk of a high import reliance for CRMs is more moderate in the chemicals sector, with strong existing mitigations in place. For example, members of the CIA have secondary sourcing strategies to proactively determine alternative sourcing solutions.[132]
High mining concentration	cobalt, graphite, platinum, palladium, silicon, nickel, hafnium, iridium rhodium, silicon	Disruption to mining activity in supply chains with a high mining concentration could lead to sustained supply-side shortages for a range of components across the UK's chemicals sector. For example, 68% of the world's silicon, one of the top ten CRMs for the chemical sector in the UK, is mined in China,[134] meaning that any decline in mining activity could impact chemicals companies further downstream.
Companion metal fraction	cobalt, iridium, palladium, hafnium, rhodium	CRMs that are mined as a secondary material in mining projects can often struggle to react to increased demand in the market, potentially leading to shortages. PGMs are used in catalysts in the chemical sector for a range of applications, such as to produce nitric acid, and are often mined as a secondary metal. For example, if mined in Russia, platinum and palladium are often extracted as a by-product nickel mining,[135] while iridium is always mined as a by-product of platinum mining, primarily in South Africa.[136]

There are greater risks from China introducing export controls than the risk of China closing the relevant mines.[133]

Figure 12: Chemicals supply risk register

Key findings

PGM catalysts are critical for the UK chemicals sector

The chemicals sector has a high dependence on PGM catalysts due to their unique properties, including high activity, selectivity, and stability. A broad range of PGM catalysts are in use across the chemicals industry today. Looking ahead, PGM catalysts are to be used in a range of green technologies and chemicals production, including Polymer Electrolyte Membrane (PEM) electrolysers and ammonia and nitric acid production.[137] PEM electrolysers will become increasingly important in the future as green hydrogen replaces fossil fuels in industrial processes and transportation, and this technology relies on platinum and iridium (and, to a lesser extent, ruthenium).

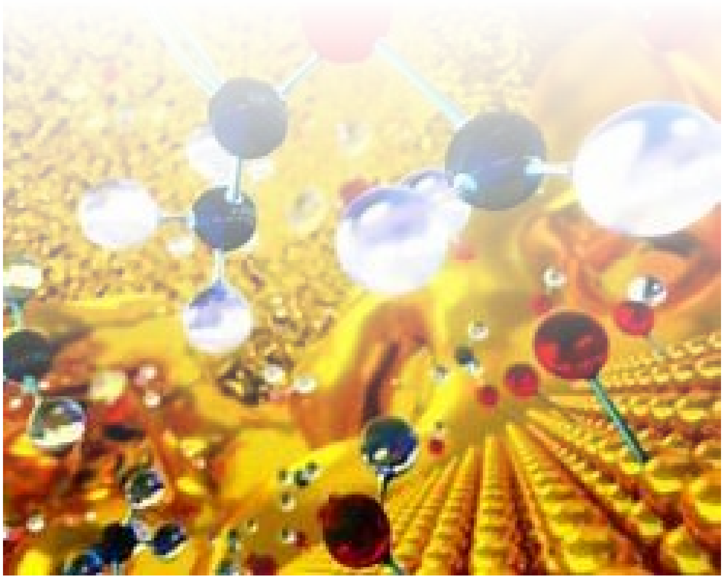
Meanwhile, catalytic convertors, used in the automotive sector to reduce ICE vehicle emissions,[138] contain platinum, palladium and rhodium. The phasing-out of ICE vehicles means that the demand for catalytic converters will fall in the next ten years, reducing the sector's dependency on palladium and rhodium.[139] However, recycling of these metals from end-of-life catalytic converters will continue for decades, meaning that they will become increasingly available for new uses, such as the production of sustainable fuels and chemicals.[140]

The UK's position in the PGM market provides a competitive advantage across these supply chains. Not only is the UK a key trading centre for these precious metals, it is also home to two of the largest producers of PGM-derived components and technologies, and the largest PGM recycler by volume (and one of the few with the capability to refine iridium and ruthenium), meaning there is already significant PGM refining, recovery and manufacturing infrastructure in the UK.[141] This will help to reduce risk and build resilience in PGM supply chains as they are increasingly used for green technologies.

131 Task & Finish Group Workshop, October - November 2023.
132 ibid.
133 ibid.
134 Publications office of the European Union, "Study on the critical raw materials for the EU 2023," European Commission, 2023
135 Paul Lusty et al., "UK criticality assessment of technology critical minerals and metals," British Geological Survey, June 30, 2022.
136 Margery Ryan, "Recycling and thrifting: the answer to the iridium question in electrolyser growth," Johnson Matthey, November 16, 2022.
137 U.S. Department of Energy, "Achieving American Leadership in the Platinum Group Metals Supply Chain," February 24, 2022.
138 Johnson Matthey, "What metal is in a catalytic converter?," Accessed October-November 2023.
139 Task & Finish Group Workshop, October - November 2023.
140 ibid.
141 ibid.

Demand for other catalysts may change in the future with economy wide implications yet to be assessed

The use of nickel, cobalt and manganese-based catalysts are also integral to the chemicals sector. Much like industrial PGM catalysts, each of these base metal catalysts have unique properties which make them suitable for specific applications. Base metal catalysts are currently more economical than their PGM-based counterparts as much lower quantities of PGMs are usually needed to catalyse a reaction as compared to the equivalent base metal catalysts. However, the economic benefits of base metals to PGMs could vary in the future as prices evolve and base metals are more difficult to recover and recycle. Key uses for base metal catalysts include processing of petrochemicals and natural gases. The applications and production of chemicals mean that supply chain disruption could have wide-reaching effects on the broader UK industry, emphasising the criticality of these dependencies.



Networks of pumps and pipework require range of materials, including CRMs to support flow of chemicals

Production of all chemicals is dependent on a network of pumps and pipework to transfer substances around manufacturing plants. Pumps and pipework are often made using specialist stainless steel alloys,[142] which have a high dependency on nickel and other alloying materials for their corrosion and heat resistance.[143] However, plastic-based pipework is also used for many chemicals, with resistance improved with plating made of metals such as copper, nickel, rhodium, and zinc.[144] As with any CRM and metal application, specific pipework is selected for specific purposes, so supply chain disruption could impact availability of materials for producing certain chemicals.[145]

The specialised applications of minerals and metals in chemicals processing means that supply chain disruption can halt operations at production plants, regardless of the quantities used. As a result, small quantities of CRMs used in niche applications can be equally as important as CRMs used in core processing machinery. However, given that chemicals companies can often require tens of thousands of suppliers to meet their input needs, diversification is embedded in sourcing strategies across the industry, boosting resilience.[146]

[141] Task & Finish Group Workshop, October - November 2023.
[142] ASM Handbook Committee, "Elevated-Temperature Properties of Stainless Steels," ASM International, 1990.
[143] Plastics Pipe Institute, "Chemical Resistance of Plastic Piping Materials," 2020.
[144] ibid.
[145] Task & Finish Group Workshop, October - November 2023.
[146] ibid.

Sector Risk Register: Electronics

Foreword

The UK Government has set out its plans to ensure that the UK remains a Science and Technology Superpower. As one of the only three countries to have its tech ecosystem valued at being worth over a £1 trillion dollars, it is essential that the UK remains able to develop, scale and adopt new technologies at pace. Many of the foundations of the wider technology sector rest on the electronics sector. From semiconductor shortages due to Covid-19 supply chain disruption that hindered the sale of the latest PlayStation through to the difficulties in sourcing leading-edge Graphical Processing Units (GPUs) due to the exponential increase in demand as a result of AI demands, it is clear that we need all need to better understand and mitigate the supply chains on which our sector depends upon.

The UK's electronic sector is heavily reliant on external suppliers of either derivatives of CRMs or components that utilise them either directly or in their manufacture – this is particularly the case in semiconductors and in compound semiconductors, an area of growing UK expertise.
The sector has taken sensible steps to attempt to mitigate further disruption but welcome the Government's initiative in this area to take a wider economic approach to ensure we deliver on the promise of being a Science and Tech Superpower.

Matt Evans
Director of Markets at TechUK

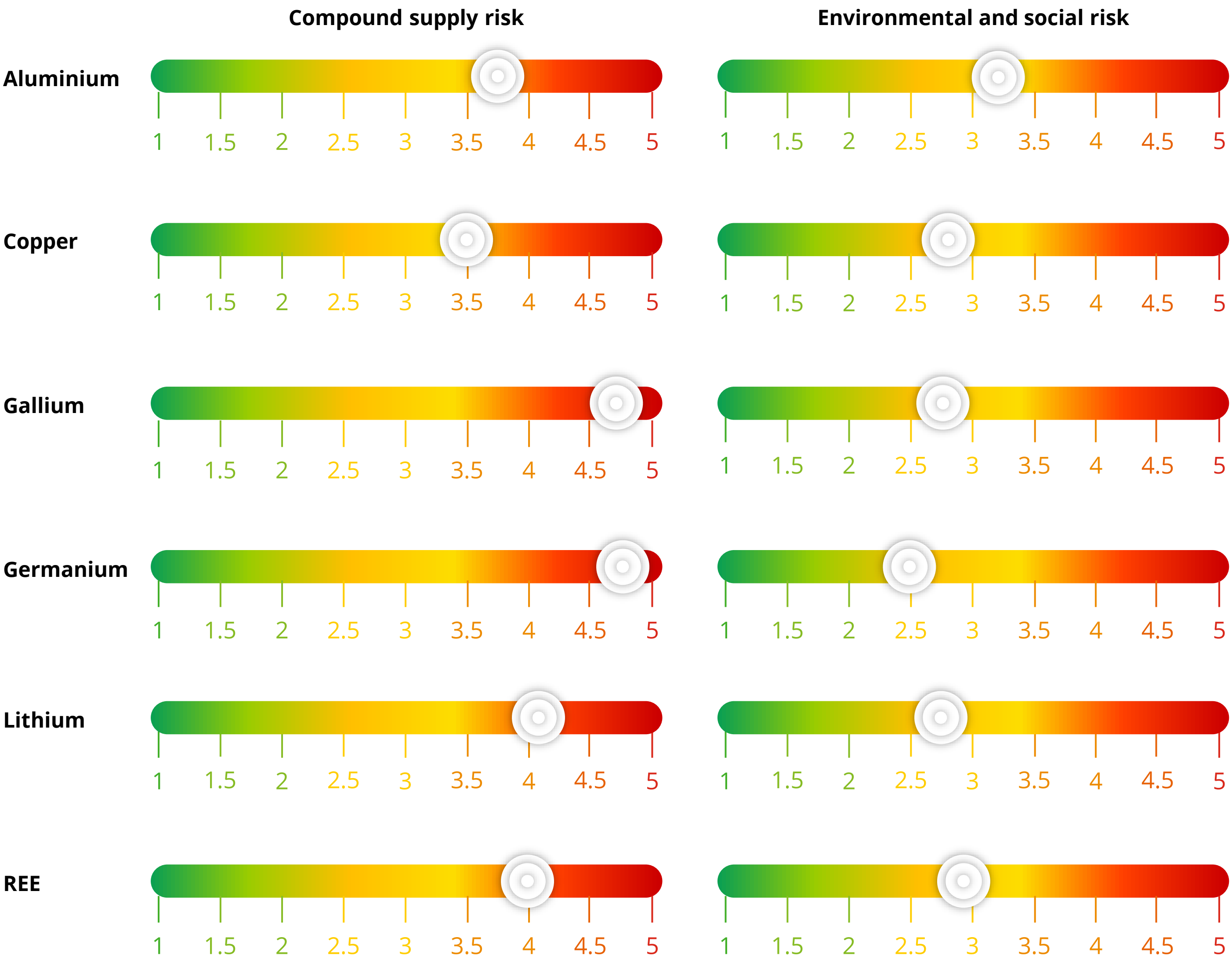
Introduction

The UK electronics industry encompasses a wide range of activities, including research, design, production, manufacture, installation, and maintenance, while playing a crucial role in supplying various industries across the global economy.[147] The industry contributes over £78 billion to the UK economy annually and is a key player in the development of emerging technologies such as 5G, the Internet of Things (IoT), and artificial intelligence (AI).[148] The industry is heavily reliant on imports, with 50% of its supply being imported and 26% of its output being exported.[149] This reliance on external suppliers increases the sectors' exposure to risks from supply chain vulnerabilities, including access to critical minerals such as copper, cobalt, silicon and tin. The minerals are essential to produce electronic devices, as well as ruthenium and palladium for high-performance, high-reliability electronics applications.[150]

Risk framework findings

This report uses a quantitative risk matrix to highlight the CRMs which pose the greatest risk to each industry (see methodology section). Figure 13 summarises the top ten CRMs for the electronics sector by overall supply risk (compound supply risk). The supply risk is calculated by multiplying the impact of a disruption to supply (material importance) by the likelihood of a disruption to supply (supply risk). In addition, the below table shows the ESG risk associated with each CRM that demonstrates the impact the material has on the environment and society.

T&F Group members from the electronics sector identified a series of CRM dependencies used to produce key materials. The chart below illustrates the materials with the highest risk profile based on the dependency of the sector on the material and the supply risk (compound supply risk), based on the risk assessment.



147 UK Government, "Electronics and Machinery Sector Report," Accessed October-November, 2023.
148 Nitronics, "The UK Electronics Industry in 2023," Accessed October-November, 2023.
149 MAKE UK, "Sector Bulletin: Electronics," Make Business, 2019.
150 Task & Finish Group Member Interview, October - November 2023

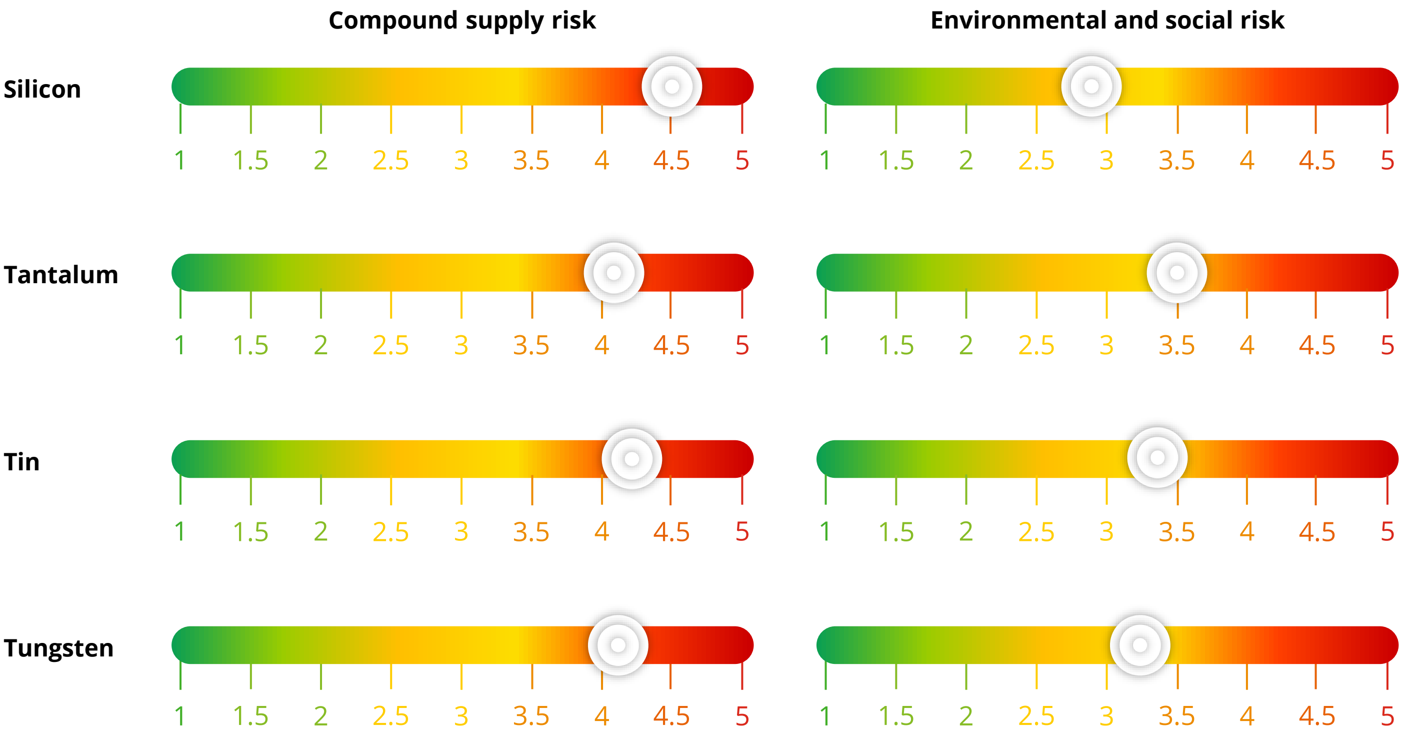


Figure 13: Electronics sector dependencies

Risk register

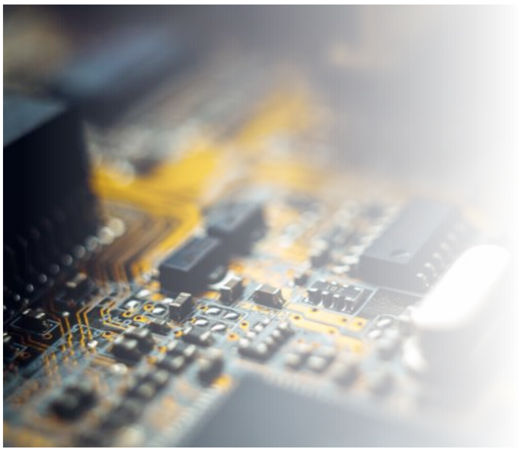
The risk register below outlines the top three supply risks to the electronics sector based on analysis of quantitative and qualitative data, including the risk assessment and T&F Group member interviews. It is important to note that the risk register selected risks based on the highest score derived from the supply risk aspect of the methodology framework. ESG risks were evaluated per mineral, not per sector, hence their exclusion from the risk register and inclusion in the earlier section. For further information on ESG risks, please refer to the environmental and social risk section on page 20.

Risk type	CRMs impacted	Risk description
Import reliance	REEs, tin, cobalt, tungsten, lithium, silicon, germanium, gallium	The UK's electronics sector is heavily reliant on external suppliers, importing 50% of its supply and exporting 26% of output.[151] This dependence on imports makes the sector more vulnerable to supply chain disruptions, including access to CRMs. While the sector in the UK does not directly rely on processed or raw CRMs, it relies on derivatives or components based on them, such as semiconductors.[152]
Mining concentration	REE, cobalt, tungsten, lithium, silicon, tungsten	Disruptions in mining activity can lead to shortages in the availability of processed resources, which can have a significant impact on the production of key components like silicon in semiconductors or tungsten in circuit boards. These CRMs are essential to the production of most electronic devices, making them vital to the sector's success.
Price volatility	cobalt, tungsten, silicon, germanium, gallium, germanium, lithium, rhodium, REEs, tin	Price volatility in CRM markets can cause significant cost challenges for electronics manufacturers. In recent years, this volatility has been the result of multiple factors, including rising demand, the Covid-19 pandemic and Russia's invasion of Ukraine.[153] While these events, amongst others, have caused significant volatility for CRMs used in the electronics sector, tin prices have been particularly affected. In 2022, LME prices dropped from a record high of $51,000 per tonne to $17,350 during the year, before bouncing back to around $24,430 by year end.[154]

Figure 13:Electornics supply risk register

[151] Department for Business and Trade and Nusrat Ghani MP, "Government ramps up supply chain work with first independent Critical Minerals Taskforce meeting," UK Government, April 20, 2023.
[152] ibid..
[153] Department for Business and Trade & Department for Business, Energy & Industrial Strategy, ""Resilience for the Future: The UK's Critical Minerals Strategy," UK Government, March 13, 2023.
[154] Andy Home, "Tin must tame its wildness to meet coming demand surge," Reuters, December 7, 2022.

Key findings



The UK is leading on R&D for semiconductors to understand the range of specialised inputs

Semiconductors, or 'chips', are key components of electronic devices used in computers, smartphones, tablets, and other consumer electronics.[155] The semiconductor industry relies on a variety of materials in different states (e.g. solids, liquids, and gases) during its manufacturing process. The material demand for each semiconductor is limited by weight or volume compared to other industrial sectors. However, at an aggregated level across the industry, the required minerals criticality, availability and demand are still significant to the overall supply chain resilience needed to support the industry.

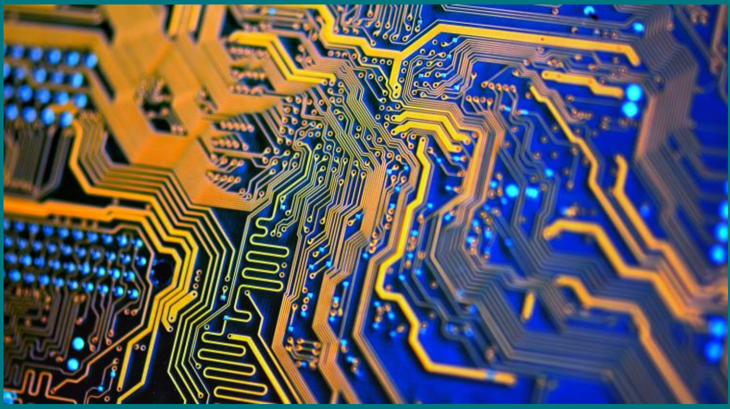
The different states of semiconductors can affect device performance, making it essential to produce consistent and reliable semiconductor devices. The challenge lies in controlling the state of the semiconductor material during the manufacturing process, as even small variations can have a significant impact on device performance and reliability.

The Covid-19 pandemic highlighted the risk of supply shortages resulting from concentrated semiconductor supply chains. The shortages highlighted the downstream implications and the increasing need for businesses to understand their supply chain from the early stages, including the sourcing of raw materials and critical components. Semiconductor production relies on silicon, germanium, and gallium, with the latter being primarily produced in China, which accounts for over 90% of the world's production.[156] The concentration of gallium production, coupled with geopolitical risk, presents risks to the electronics industry. For example, in August 2023 China introduced restrictions on the exports of gallium.[157]

Over time, manufacturing hubs in Taiwan have established significant industry dominance, and other key materials and components in the supply chain are highly concentrated in single companies or countries.[158] The UK does not have a significant share of global silicon semiconductor manufacturing compared with the existing advanced silicon manufacturing capabilities in East Asia. Instead, industry experts have identified that the UK can focus on pursuing alternative opportunities within the sector. A particular area highlighted was chip design, where the UK has an existing comparative advantage.[159] The UK Government has announced plans to invest in the semiconductor industry as part of its efforts to boost the country's high-tech manufacturing capabilities, which includes funding of up to £1 billion to support the development of new technologies, including semiconductors, as well as the creation of new R&D centres.[160] These initiatives are aimed at strengthening the UK's position as a leader in the semiconductor R&D industry and promoting resilience in UK supply chains.

[155] McKinsey & Company, "The semiconductor decade: A trillion-dollar industry," April 1, 2022.
[156] Zeyi Yang, "China just fought back in the semiconductor exports war. Here's what you need to know," July 10, 2023.
[157] Annabelle Liang and Nick Marsh, "Gallium and germanium: What China's new move in microchip war means for world," BBC News, August 2, 2023.
[158] Akhil Thadani and Gregory Allen, "Mapping the Semiconductor Supply Chain: The Critical Role of the Indo-Pacific Region," May 30, 2023.
[159] Department for Science, Innovation and Technology "National semiconductor strategy" UK Government, May 19, 2023.
[160] ibid.

A greater role for hafnium in computing?



Hafnium oxide is used as a dielectric material in electronic devices, such as resistive random-access memory (RRAM) which is an important component to computers.[161] In RRAM, hafnium oxide separates the two electrodes and enables the storage of data. When a voltage is applied to the electrodes, a conductive filament is formed in the hafnium oxide layer, which changes the resistance of the memory cell.[162] It is these different resistance states that can be used to store data.

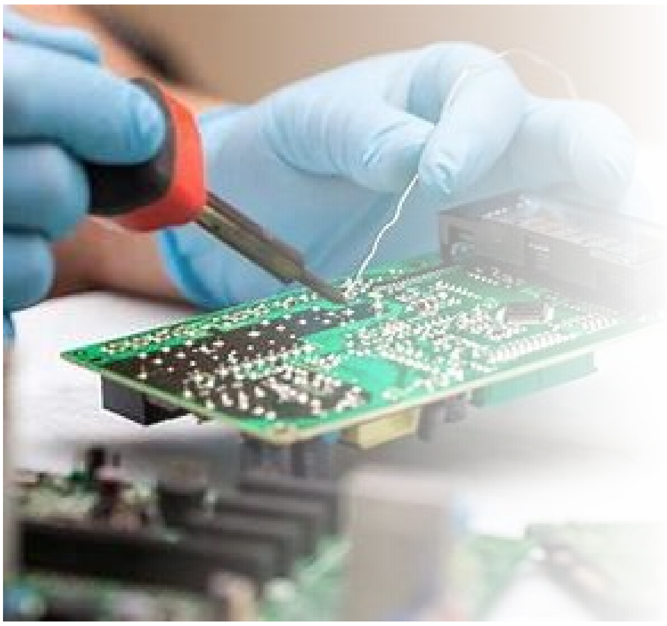
Researchers from the University of Cambridge, UK have developed a prototype device that processes data similarly to synapses in the human brain through the use of hafnium oxide. This approach along with small self-assembled barriers that can be raised or lowered to allow electrons to pass.[163] The researchers found that by adding barium to thin layers of hafnium oxide, vertical and highly-structured barium-rich 'bridges' are created that allow electrons to pass through, while the surrounding hafnium oxide stays unstructured.[164]

An energy barrier is created at the point where these bridges meet the device contacts, which can be crossed by electrons. The height of this barrier can be controlled to change the electrical resistance of the composite material, which enables multiple states to exist in the material, unlike conventional memory that only has two states.[165] Due to its ability to self-assemble at low temperatures, hafnium oxide shows great promise for next-generation memory applications, offering high performance and uniformity.

This new design for computer memory has the potential to significantly improve performance and reduce energy consumption in internet and communication technologies, which are projected to consume almost one-third of global electricity over the next decade.[166] This is important as the rising demand for hafnium oxide has resulted in a shortage in the market, leading to exorbitant price increases.[167]

[162] Karsten Beckmann et al., "Nanoscale Hafnium Oxide RRAM Devices Exhibit Pulse Dependent Behaviour and Multi-level Resistance Capability," MRS Advances, May 20, 2016.
[163] ibid.
[164] Markus Hellenbrand et al., "Thin-film design of amorphous hafnium oxide nanocomposites enabling strong interfacial resistive switching uniformity.," Science Advances, June 23, 2023.
[165] ibid.
[166] Karsten Beckmann et al., "Nanoscale Hafnium Oxide RRAM Devices Exhibit Pulse Dependent Behaviour and Multi-level Resistance Capability," MRS Advances, May 20, 2016.
[167] Markus Hellenbrand et al., "Thin-film design of amorphous hafnium oxide nanocomposites enabling strong interfacial resistive switching uniformity.," Science Advances, June 23, 2023.
[168] Picture Source: https://www.wallpaperbetter.com/en/hd-wallpaper-uqwek.

Currently, electronics have a non-substitutable requirement for conflict minerals



Society's demand for electronic devices has, in turn, led to increased demand for tin, tantalum, and tungsten – often referred to as conflict minerals.[169] Conflict minerals carry a higher level of risk due to the ethical concerns associated with their origins and supply chain transparency. Conflict minerals are typically sourced from regions with risks such as political instability, armed conflict, exploitation, or human rights abuses.[170] As a result, the use of minerals from such regions may lead to legal and reputational risks for companies, as consumers and investors expect ethical sourcing practices, alongside increasing regulation for responsible supply chains, such as the EU's policy related to deforestation.

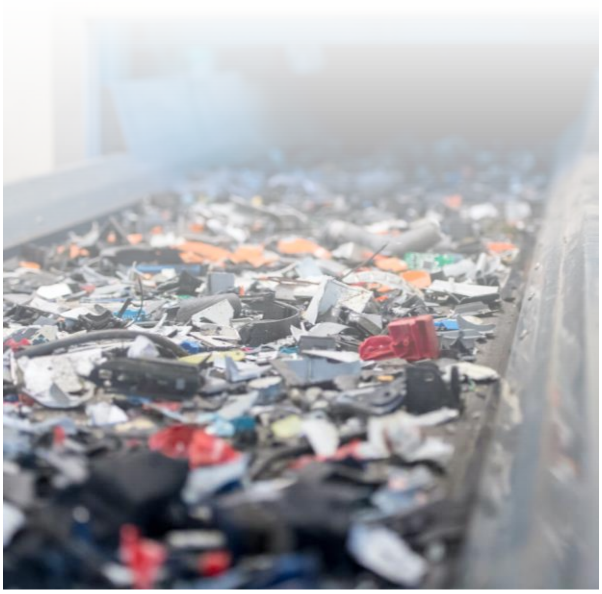
- Tin is widely used in the electronics sector as a coating material for electronic components and as a soldering material for joining electronic components to circuit boards.[171] Compared to some of the other minerals highlighted in this report, the mining of tin is not as concentrated in one country. As a result, the risks impacting the supply chain will be specific to the region and origin of the mineral. For example, tin mining in Bolivia involves risk of child labour and hazardous working conditions, including inadequate safety equipment, poor ventilation, and insufficient lighting, which pose various health and safety risks to both children and adults working in artisanal or abandoned mines.[172]
- Tantalum is primarily extracted from minerals such as coltan (columbite-tantalite), tantalite, and euxenite.[173] It is a fundamental component of tantalum capacitors, which are widely used in electronic devices such as smartphones and computers due to their high capacitance, stability, and long lifespan.[174] However, 35% of global tantalum is mined in the Democratic Republic of Congo (DRC),[175] a region that has a history of documented ethical issues in the mining industry. The abundance of natural resources in the DRC has historically been utilised to finance wars, armed conflicts, and state development, often at the expense of human rights.[176] In particular, mining activity in the DRC has been linked to adverse impacts on the health, safety and well-being of miners and surrounding communities.[177]
- Tungsten is used in the production of filaments for incandescent light bulbs, cathodes for electronic devices, and electrical contacts and electrodes.[178] Tungsten mining in the DRC has been associated with human rights abuses, including forced labour and child labour.[179] In addition, the use of toxic chemicals – such as cyanide and sulphuric acid – in the extraction and processing of tungsten can lead to water and soil contamination, which harms local ecosystems and wildlife. Exposure to tungsten through inhalation or physical contact with polluted soil has been shown to impact human health, with studies revealing that excess exposure can lead to leukaemia and lung toxicity.[180]

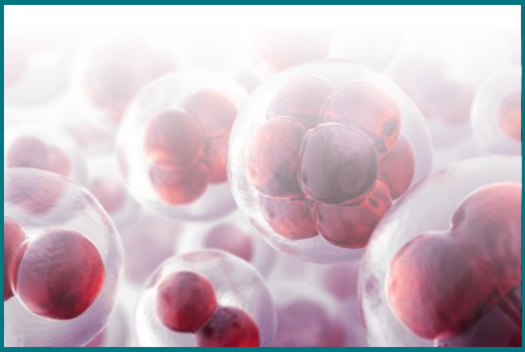
To help mitigate the environmental and social risks associated with conflict minerals, the UK has committed alignment with the EU Conflict Mineral Regulation, which aims to ensure responsible sourcing practices.[181]

[169] Acquis, "The Similarities and Differences between US & EU Conflict Minerals Regulations," Accessed October-November, 2023.
[170] European Commission, "Conflict Minerals Regulation: The regulation explained," Accessed October-November, 2023.
[171] Edison, "Tin," April 12, 2021.
[172] Verité "Countries where Coltan, Tungsten & Tin are Reportedly Produced with Forced Labor and/or Child Labor," Accessed October-November 2023.
[173] Klaus Schulz, Nadine Piatak and John Papp, "Niobium and tantalum," U.S. Geological Society, 2017.
[174] Jenna Marie Goldblatt, "Conflict and Coltan: Resource Extraction and Collision in The Democratic Republic of the Congo and Venezuela," Fordham Research Commons, May 19, 2023.
[175] Publications office of the European Union, "Study on the critical raw materials for the EU, 2023," European Commission, 2023.
[176] Jenna Marie Goldblatt, "Conflict and Coltan: Resource Extraction and Collision in The Democratic Republic of the Congo and Venezuela," Fordham Research Commons, May 19, 2023.
[177] Jenna Marie Goldblatt, "Conflict and Coltan: Resource Extraction and Collision in The Democratic Republic of the Congo and Venezuela," Fordham Research Commons, May 19, 2023.
[178] Special Metals Fabrication, "Is Tungsten the Right Metal for my Application?," February 28, 2019.
[179] U.S. Department of State, "Trafficking in Persons Report," June 2019.
[180] Sija Liu et al., "Soil tungsten contamination and health risk assessment of an abandoned tungsten mine site," Science of The Total Environment, December 15, 2022.
[181] European Commission, "Conflict Minerals Regulation: The regulation explained," European Union, Accessed October-November, 2023.

E-waste provides opportunity for the UK, but requires Government leadership and strategy

E-waste, or Waste Electric and Electronic Equipment (WEEE), refers to all types of old, discarded or end-of-life electrical and electronic equipment.[182] The rapid technological innovations and increasing demand in the electronics sector have led to a rise in the generation of WEEE.[183] The UK generates around 24kg of WEEE per-capita annually and only recycles just over half of this.[184] In a move to address increasing levels of WEEE, the UK Government has implemented regulations that require electronic equipment producers to take responsibility for their products' collection, treatment, and recycling. However, collection of e-waste remains a challenge, with much waste ending up in landfill or left in people's drawers.[185] While these regulations have been around for a long time, there is a need to update them. The UK Government has been looking to address this with a consultation on extended producer responsibility for WEEE which was initially scheduled for release in 2020 but is yet to be published.





Using non-toxic bacteria for recycling

Coventry University's bioleaching process is a sustainable and environmentally friendly method for extracting metals from WEEE. Developed by researchers at the university, this process uses bacteria to dissolve metals from WEEE, without the use of harmful chemicals or high temperatures.[186]

Traditional methods of extracting metals from WEEE involves the use of chemicals or high temperatures. Coventry University's bioleaching process could be a safer and more sustainable alternative which would produce no harmful by-products and ensures a minimal carbon footprint.

The process involves the use of non-toxic bacteria, including Acidithiobacillus ferrooxidans, which are able to dissolve metals from WEEE into an oxidised solution.[187] The bacteria are added to a solution containing WEEE, and over time break down the metals into a soluble form that can be easily extracted.[188] The process has been successfully tested on a range of WEEE, including printed circuit boards and mobile phones. While bioleaching has been used for many years in the mining industry, Coventry University's process is the first industrial application to address the issues of WEEE recycling.[189]

[182] Arda Işildar, Eldon Rene, Eric van Hullebusch, Piet Lens, "Electronic waste as a secondary source of critical minerals: Management and recovery technologies," Resources, Conversation and Recycling, August 2018.
[183] World Economic Forum, "A New Circular Vision for Electronics, Time for a Global Report," January, 2019.
[184] ITU, "Global E-Waste Monitor 2020," Accessed October-November 2023.
[185] World Economic Forum, "A New Circular Vision for Electronics, Time for a Global Report," January, 2019.
[186] Coventry University, "Bioleaching technology for the recovery of metals from Electronic Waste- Research Project," Accessed October-November 2023.
[187] Coventry University, "Bacteria can recover precious metals from electronic vehicle batteries," July 20, 2021
[188] Coventry University, "Researchers are developing ways to recycle electronics using bacteria," January 22, 2020.
[189] ibid.

Sector Risk Register: Energy

Foreword

To achieve the transition to net zero and clean energy will require enormous investments into renewable power generation, grid infrastructure and installation equipment. We need to ramp up renewable energy, electricity transmission and distribution, energy storage, electric vehicle charging, heat pumps and other green heating methods and upgrade our electrical installations to allow use of clean technology.

There will be enormous dependence on CRMs that already have scarce and limited supply. The need for new battery technology means that UK production is already concerned over availability of minerals such as lithium and cobalt. We must also be alerted to risks to strategic materials that currently have sufficient supply but where this will be restricted by other markets as global demand increases.

There are forecasts of significant shortages of supply for vital metals such as copper and aluminium throughout Europe due to the increasing demand for such materials for manufacturing in China. There is scope for much greater recycling of such metals but again this is often sent overseas for processing and effectively lost to UK manufacturing.

The UK energy industry has made strides to make supply chains more resilient to such challenges but in many cases, this has reached natural limits. A Government initiative to examine this with a sense of urgency is essential.

Andrew Willman

Chief Operating Officer of BEAMA

Introduction

The energy sector is represented on the T&F Group across four key areas: wind energy, solar energy, nuclear energy, and hydrogen. The UK's dependence on these, and other green energy sources, will grow significantly in the coming decades as the sector phases-out fossil fuel energy sources to achieve net-zero by 2050. There is a vast mix of CRM dependencies across these different energy sources, and it is vital that each sub-sector secures the types and volumes of CRMs that it needs to meet Government targets. The expansion of green energy infrastructure also needs to be matched by equal growth in the UK's electric transmission networks and battery energy storage systems (BESS). While transmission and BESS were not in-scope for this report, it is important to note that the expansion of the grid and energy storage infrastructure will require significant volumes of copper and aluminium wiring and battery metals respectively, allowing new electricity generators to produce and store clean energy.

Risk register

The risk register below outlines the top three supply risks to the energy sector based on analysis of quantitative and qualitative data, including the risk assessment and T&F Group member interviews. It is important to note that the risk register selected risks based on the highest score derived from the supply risk aspect of the methodology framework. ESG risks were evaluated per mineral, not per sector, hence their exclusion from the risk register and inclusion in the earlier section. For further information on ESG risks, please refer to the environmental and social risk section on page 20. Unlike the other sector sections in this report, this section will delve into the risk register before addressing the risk frameworks. This is because wind energy, solar energy, nuclear energy, and hydrogen all have their own risk frameworks, while the sectors share a risk register.

Risk type	CRMs impacted	Risk description
High import reliance	cobalt, gallium, indium, silicon, vanadium, platinum iridium, molybdenum, REEs	Energy independence for the UK economy means reducing reliance on imported power sources and onshoring domestic power generation. While renewable energy production supports this objective, the UK must first import the CRMs and components that comprise renewable energy infrastructure. For example, given the UK's target to reach 50 GW of offshore wind capacity by 2030, and 70 GW of solar photovoltaic capacity by 2035,[190] the respective imports of permanent magnets and polysilicon will be key. However, imports such as these could be subject to a range of risks that impact supply, including resource nationalism and market manipulation,[191] potentially impeding the UK's energy transition.
Companion metal fraction	cobalt, gallium, indium, iridium, tellurium	CRMs that are mined as a secondary material can often struggle to react to increased demand in the market, potentially leading to shortages. Several metals used for renewable energy technologies are mined in this way, meaning that as the UK faces increased competition from other CRM importers so the energy sector may struggle to secure supplies of certain inputs. As an example, indium, which is used in copper indium gallium selenide (CIGS) solar cells, is primarily produced as a by-product of zinc mining.[192]
Regulations and sanctions	aluminium, copper, nickel, platinum, gallium, zinc	Inadequate preparedness for, and management of, trade regulations and sanctions could lead to a breakdown in CRM supply chains, creating challenges for, among others, power generators and energy OEMs. An example of this can be seen in the solar energy sector, which was hit by Chinese export controls on gallium in mid-2023,[193] with downstream consequences on the production of gallium arsenide solar cells.
Low recycling rates	boron, REEs, silicon, tellurium, zirconium	Low recycling rates for CRMs can impede the energy sector's move towards closed-loop supply chains, especially as old infrastructure is decommissioned, and new infrastructure is installed. This could maintain the UK's high reliance on imports of virgin materials for the expansion of wind, solar, nuclear and hydrogen capacity. Permanent magnet recycling is a key example of this and demonstrates where current infrastructure needs to be improved to recover the REEs from decommissioned wind turbines in the future (*see Hypromag REE Magnet Recycling case study in the Automotive section).*

Figure 15: Energy supply risk register

Hafnium is still needed for gas turbines

Hafnium is not included in this table, as this section focuses primarily on the energy transition. Nevertheless, hafnium is required for gas turbines, which are still among the biggest generator of power in the UK today. However, the tides are turning. Almost a third (32.4%) of energy was supplied from wind energy in the first quarter of 2023, outpacing gas (31.7%). This is the first-time wind provided the largest share of power in any quarter in the country's electricity grid.[194]

[190] Chloe Forrester, "Where will Britain's future energy supply come from,?" House of Commons Library, May 12, 2022.
[191] IRENA, "Geopolitics of the energy transition: Critical materials," International Renewable Energy Agency, 2023.
[192] Paul Lusty et al., "UK criticality assessment of technology critical minerals and metals," British Geological Survey, June 30, 2022.
[193] Reuters, "China gallium, germanium export curbs kick in; wait for permits starts," August 1, 2023.
[194] Drax, "Wind powers Britain more than gas for first time," May 10, 2023.

Risk framework for the energy sector

This report uses a quantitative risk matrix to highlight the CRMs which pose the greatest risk to each industry (see methodology section). Figures 16-19 summarise the top ten CRMs for the energy sectors by overall supply risk (compound supply risk). The compound supply risk comprises two scores: 1) material importance (the impact of a disruption in supply on the energy sector), which was determined by stakeholder inputs; and 2) supply risk (the likelihood of a disruption given the material specific risk factors), which was derived from secondary data sources in the risk assessment. These two scores were multiplied to reach the compound risk score shown. In addition, the charts show the environmental and social risk associated with each CRM and demonstrates the impact a CRM has on the environment and society.

Wind energy

Risk framework findings

Figure 16 below shows the top five CRM dependencies and risk scores for the wind energy sector.

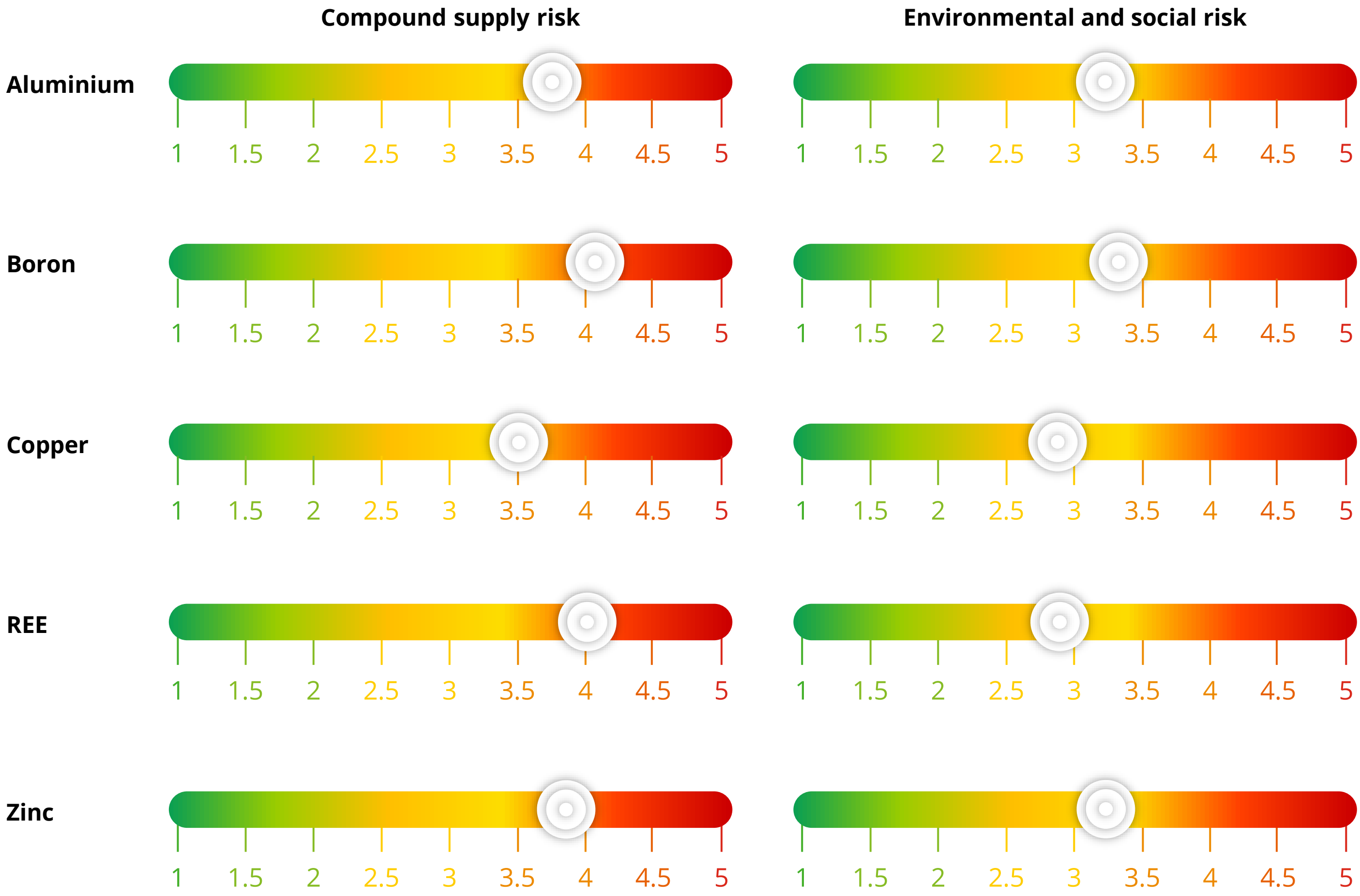
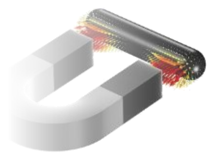


Figure 16: Wind energy sector dependencies

Key findings

Permanent magnets needed in the installation of wind turbines with the UK leading on innovation to develop alternatives

Permanent magnets are an integral component in many wind turbine generators. They are typically made using an alloy of REEs (neodymium, dysprosium), iron and boron (Nd-Fe-B type magnets)[195] and are used to enhance the performance of wind turbines through efficiency gains and design simplification. It is estimated that to install 75 GW of offshore wind energy, the UK will require 93,000 tonnes of permanent magnets,[196] which typically weigh between 2-4 tonnes per offshore wind turbine.[197] Considering that a Nd-Fe-B magnet is 28.5% neodymium and 4.4% dysprosium,[198] this creates a significant dependency on REEs for the UK's wind sector, which will be a core pillar of the future energy mix.



Companies are actively working to develop alternative materials in permanent magnets – including a UK-based company that has designed a REE-free wind turbine generator with a 15 MW capacity[199] – but the REE-free magnets currently available do not have the necessary power for commercial use in offshore wind. This may change in the long-term depending on research outcomes. However, the wind sector should be aware of any new dependencies which may arise through substitution, and the potential impact that shifts in demand could have on market volatility.[200]

Other companies are working on REE processing and recycling in the UK as a solution for supply chain challenges (see Future Trends). This will help bolster UK REE resilience by using closed-loop supply chains and reduce the environmental and social impacts associated with mining and processing virgin REEs, including the production of radioactive waste.[201]

Components needed often must be imported with limited upstream visibility

While there are some OEM manufacturing sites in the UK, many wind turbine components are imported from mainland Europe, using minerals and metals produced in China.[202] Sector representatives highlighted that there is limited visibility over of these stages of the supply chain, potentially leaving companies exposed to unforeseen disruption. This could create challenges in the context of the UK's energy security and net-zero targets. It may also point to the challenges that companies face regarding oversight of the environmental and social impacts of their CRM inputs. To elevate industry understanding of such impacts, companies should consider focusing on improving upstream transparency.

Design of UK financing and contracts for power generation may limit turbines' useful life

In a circular economy, alongside designing out waste and recovering and recycling, another effective way to conserve CRMs is to keep assets in use for as long as possible.[203] There is currently a significant gap in the length of Contracts for Difference (CfD) – a financial instrument which reduces risk by providing a guaranteed price for wind energy over a set period – compared to the potential life of wind turbines.[204] Under current terms, the UK Government awards 15-year CfDs to power generators.[205] However, the useful life of modern wind turbines is 25 years and beyond, and the next generation are expected to have capacity for 35 years of service with some stakeholders suggesting that this could increase to 50 with the right incentives and maintenance.[206]

This currently means that windfarms may be decommissioned prematurely, resulting in the removal of turbines which are either operable or have potential for life extension,[207] therefore limiting the resource optimisation of CRMs within the turbines. As such, there is an opportunity to assess whether CfDs can be extended to prolong the life of windfarms, or whether other financial instruments can be used to continue to provide a guaranteed energy price beyond the length of the CfD. This will help maximise the use of CRMs in the wind sector in the long-term; minimise damage to the seabed; and continue to support energy security and decarbonisation in the UK.

[195] University of Birmingham, "Securing Technology-Critical metals for Britain," Accessed October-November 2023.
[196] Task & Finish Group Workshop, October - November 2023.
[197] Wiebke Rabe, Genia Kostka, Karen Smith Stegen, "China's supply of critical raw materials: Risks for Europe's solar and wind industries?," Energy Policy, February 1, 2017.
[198] ibid.
[199] GreenSpur, "GreenSpur Wind and Niron Magnetics Collaborate to Develop New Rare Earth-free Generator Solution for the Offshore Wind Market," July 28, 2022.
[200] Task & Finish Group Workshop, October - November 2023.
[201] Petra Zapp et al., "Environmental impacts of rare earth production," MRS Bulletin, March 17, 2022.
[202] Task & Finish Group Workshop, October - November 2023.
[203] Ellen Macarthur Foundation, "Towards the circular economy Vol. 1: an economic and business rationale for an accelerated transition," 2013.
[204] Task & Finish Group Workshop, October - November 2023.
[205] Department for Business, Energy and Industrial Strategy (BEIS), "Evaluation of the Contracts for Difference scheme," UK Government, March 2021.
[206] Task & Finish Group Workshop, October - November 2023.
[207] Tony Fong, "Monopile Remaining Useful Life Assessment Scoping Study Summary," University of Hull, September 2018.

Solar energy

Risk framework findings

Figure 17 below shows the top five CRM dependencies and risk scores for the solar energy sector.

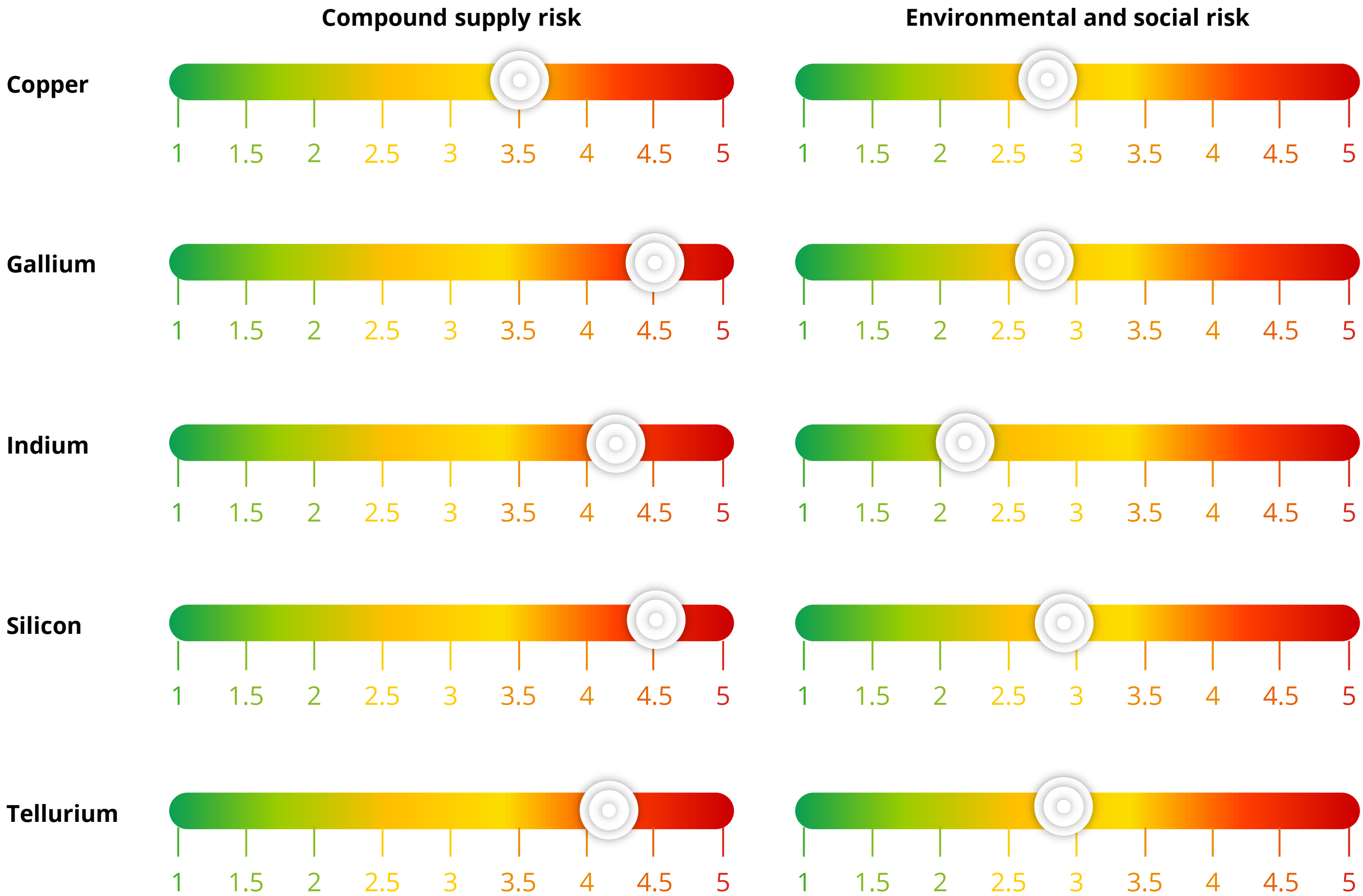


Figure 17: Solar energy sector dependencies

Key findings

Different types of solar cells show different dependencies on CRMs

Crystalline silicon solar cells currently account for more than 90% of the photovoltaics market due to their high efficiency and long lifespan.[208] This efficiency level is constantly improving, with current crystalline silicon solar cells able to achieve laboratory efficiency of 25%.[209] It is forecasted that this dominance of the solar photovoltaics market will continue in the future, with significant manufacturing capacity already in place and further investments being made into new facilities.[210] However, while crystalline silicon solar cells have driven the global uptake of solar energy, there are other photovoltaic technologies which have different CRM dependencies. Included in these technologies are copper indium gallium selenide (CIGS) and gallium arsenide solar cells. While CIGS and gallium arsenide solar cells are preferable to crystalline silicon in some respects due to their superior flexibility[211] and efficiency,[212] their reliance on gallium creates additional supply chain risk. It is likely that these technologies will be used in more specialised applications in the future.

[208] Justyna Pastuszak and Pawel Wegierek, "Photovoltaic Cell Generations and Current Research Directions for Their Development," August 12, 2022.
[209] Sami Iqbal et al., "9 - Advances in solar cell fabrication and applications using nanotechnology," Materials Technologies and Applications, June 5, 2023.
[210] Task & Finish Group Workshop, October – November, 2023.
[211] Friedrich Kessler and Dominik Rudmann, "Technological aspects of flexible CIGS solar cells and modules," Solar Energy, 25 May, 2004.
[212] Nikola Papež, "Overview of the Current State of Gallium Arsenide-Based Solar Cells," Materials, June 4, 2021.

Input materials for photovoltaics dependent on Xinjiang

Xinjiang province in China produces around 35% of the world's polysilicon – a key material used in the production of crystalline silicon solar cells.[213] As such, the province is deeply embedded in global photovoltaics supply chains. This represents a risk for the UK's solar energy sector due to widely cited concerns around forced labour in the region.[214] However, efforts led by the Solar Stewardship Initiative (SSI) are hoping to address this risk. The SSI emphasises the need to improve transparency and promote responsible sourcing in solar PV value chains, and seeks to enable this through greater industry collaboration, standards, and certifications.[215] While the SSI represents an industry-led solution in the UK and Europe, the US has adopted a legislative approach under the Uyghur Forced Labour Prevention Act, which asks companies to provide compelling evidence that no forced labour was used in the production of products.[216]

Wide use of solar panels creates urgent need for greater focus on ability and demand to deliver recycling capability

Many solar panels installed in the last two decades will soon be at end of life (EoL), creating significant volumes of WEEE that the sector will need to manage. According to IRENA, the UK will generate at least 30,000 tonnes of solar panel waste in the next decade, which will surge post-2030 as panels from the 2000s are decommissioned.[217] By 2050 this could cumulatively reach up to 1.2 million tonnes.[218]

To ensure that this waste is responsibly managed, and that CRMs are recovered for new uses, the UK will need to establish new policy and infrastructure for reuse and recycling in the coming years. As a first step, the focus should be on establishing a clear view of solar panel decommissioning dates to understand when infrastructure will need to be in place. Failure to do so would represent a missed opportunity to embed circularity in solar panel value chains and could result in huge volumes of solar panels being illegally discarded.

[213] UK Parliament, "Joint Submission to the Call for Evidence on Critical Minerals," February 28, 2023.
[214] Laura Murphy & Nyrola Elimä, "In Broad Daylight Uyghur Forced Labour and Global Solar Supply Chains," Sheffield Hallam University Helena Kennedy Centre for International Justice, 2021.
[215] Solar Stewardship Initiative, "Driving a more responsible transparent, and sustainable solar value chain," Accessed October-November, 2023.
[216] U.S. Customs and Border Protection, "Uyghur Forced Labor Prevention Act," Accessed October-November, 2023.
[217] By Resource, "The Challenges of Solar Panel Recycling," January 9, 2023.
[218] IRENA, "End-of-life management: Solar Photovoltaic Panels," International Renewable Energy Agency, June, 2016.

Nuclear energy

Risk framework findings

Figure 18 below shows the top five CRM dependencies and risk scores for the nuclear energy sector.

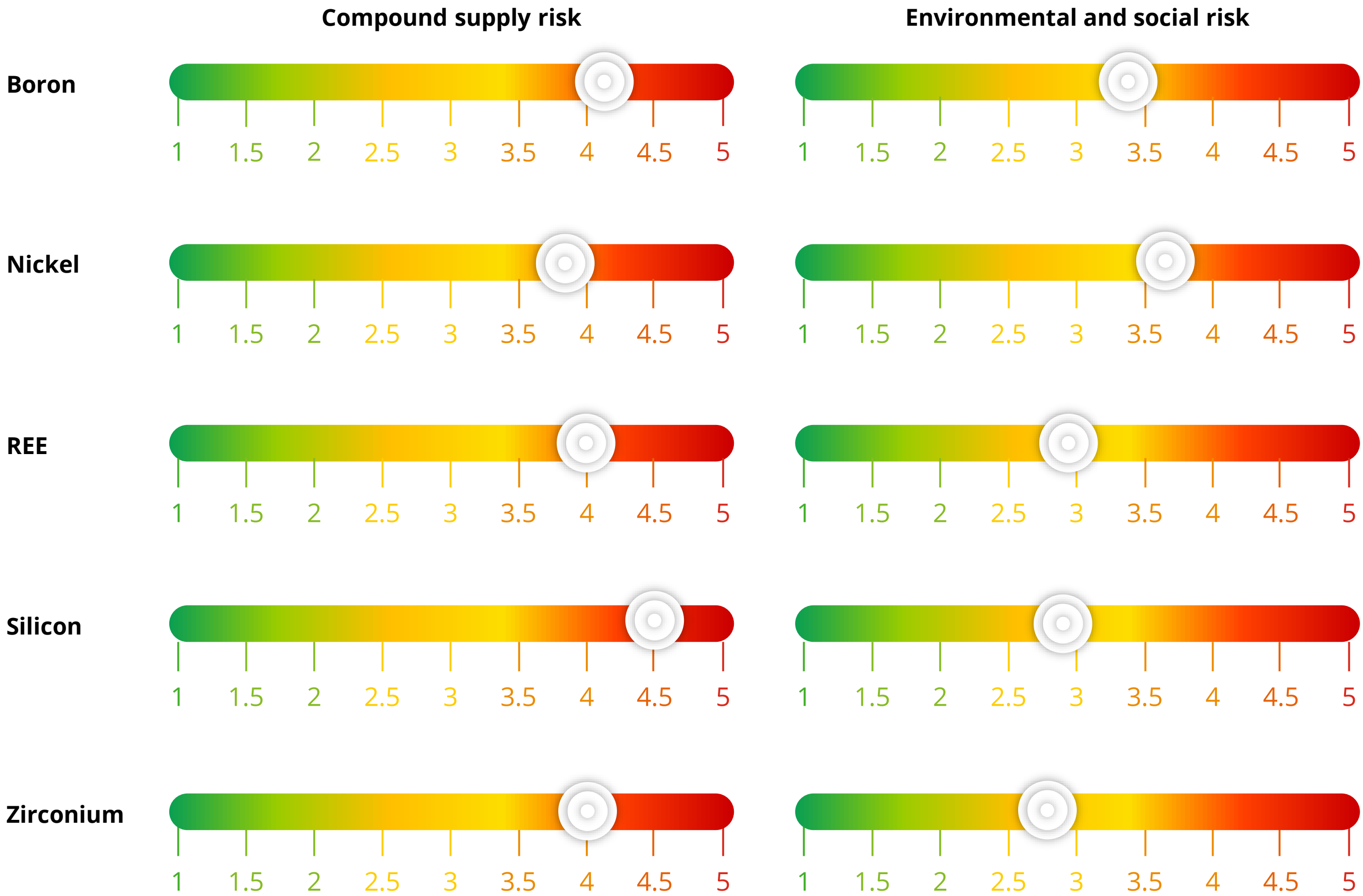


Figure 18: Nuclear energy sector dependencies

In addition to the minerals and metals in Figure 18, the nuclear energy sector has a dependence on a range of other minerals and metals. Included in these are graphite, lithium, indium, and REEs.

Key findings

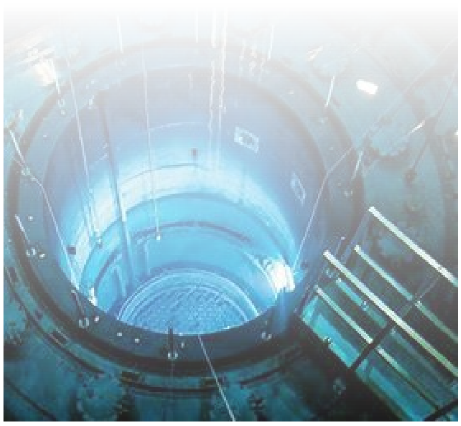
Fuel rod cladding important safety feature for nuclear power generation

Nuclear fuel rod cladding is a key safety feature of nuclear energy reactors. It can be seen as the outer jacket of a fuel rod that keeps the fission products isolated from the surrounding environment and must have high mechanical strength and strong heat resistance.[219] A zirconium-based alloy called zircaloy has traditionally been used as the core material in fuel rod cladding, due to its neutron transparency and high corrosion resistance.[220] Zirconium supply chains are generally lower risk than some other CRMs, with more than half of the mines located in Australia and South Africa.[221] Nickel-based superalloys and silicon carbide can also be used as cladding material for nuclear fuel rods,[222] with the latter emerging as a strong candidate to replace zircaloy in the future.[223] While silicon carbide cladding is still in the research phase, it may yet change the sector's fuel cladding dependencies should it prove commercially viable.

[219] Cesar Azevedo, "Selection of fuel cladding material for nuclear fission reactors," Engineering Failure Analysis, June 21, 2011.
[220] Rion Causey, Richard Karnesky & Chris San Marchi, "4.16 - Tritium Barriers and Tritium Diffusion in Fusion Reactors," February 10, 2012.
[221] Publications office of the European Union, "Study on the critical raw materials for the EU 2023," European Commission, 2023.
[222] Task & Finish Group Workshop, October – November, 2023.
[223] Peter Dunn, "Silicon carbide cladding proves its mettle," Department of Nuclear Science and Engineering Massachusetts Institute of Technology, Accessed October-November, 2023.

A transition in the UK's nuclear power plants may shift the risks associated with the UK's graphite dependency

The core function of a nuclear moderator is to slow down fast-moving fission neutrons inside a nuclear reactor. A range of materials can be used in nuclear moderators,[224] including graphite, heavy water, and sodium,[225] all of which have a low neutron absorption cross-section. The UK traditionally used graphite as a moderator material in the previous generation of nuclear power stations, but potential for cracking as the reactor aged has created scepticism about using it in the future.[226] Instead, the next generation of the UK's nuclear power plants will be light water reactors,[227] meaning that risks associated with a high graphite dependency should not impact the sector in the future.

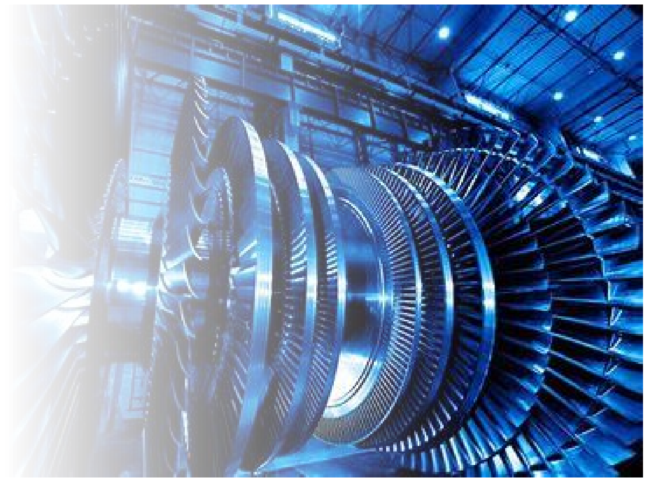


Control rods use of boron creates concern given concentrated market raising need for other CRMs use in rods

The purpose of nuclear control rods is to prevent fission reactions from accelerating beyond control.[228] While there are various CRMs that can be used in these control rods, such as cadmium, hafnium and gadolinium,[229] nuclear power stations have typically chosen to use boron.[230] All control rod materials are selected for their neutron absorption properties and ability to alter reaction speeds. However, the highly concentrated market for boron, and its' even greater reserves concentration (Turkey has almost 90% of all known reserves[231]), means it could be subject to greater supply challenges in the future; especially due to the rising international competition in a highly concentrated market.[232]

Steam turbines' exposure to harsh environment limits using wide range of CRMs in their design

Steam turbines are key in the conversion of heat energy into electrical energy in nuclear power stations. Like other high-performance turbines, including those used in fossil fuel power plants, steam turbines in nuclear power generation are exposed to harsh environments which require high strength and corrosion resistance. This makes nickel-based alloys integral to maintaining the high performance of steam turbines.[233] If exposed to particularly high temperatures, the use of chromium is also common.



[224] C.K. Gupta, "Nuclear Reactor Materials," Encyclopaedia of Materials: Science and Technology, January 1, 2003.
[225] Pratik Joshi, Nilesh Kumar, Korukonda Murty, "Materials of Nuclear Reactors," Encyclopedia of Materials, Metals and Alloys, September 1, 2021.
[226] Office for Nuclear Regulation, "Graphite core of AGRs," Accessed October-November, 2023.
[227] Chris Matthew and Alan Walker, "Nuclear energy in the UK," UK Parliament, December 12, 2022.
[228] Medhat Hasssan & Heba Louis, "Control rod material effect on safety parameters of research reactors," Kerntechnik, May 21, 2019.
[229] Nuclear Decommissioning Authority, "Understanding activities that produce radioactive wastes in the UK," Accessed October-November, 2023.
[230] Task & Finish Group Workshop, October – November, 2023.
[231] Mingxue Zue et al., "International trade evolution and competition prediction of boron ore: Based on complex network and link prediction," Resources Policy, April 21, 2023.
[232] ibid.
[233] Gordon Holcomb, "Alloys for advanced steam turbines- oxidation behaviour," National Energy Technology Laboratory, October 1, 2007.

Hydrogen

Risk framework findings

Figure 19 below shows the top five CRM dependencies and risk scores for the hydrogen energy sector.

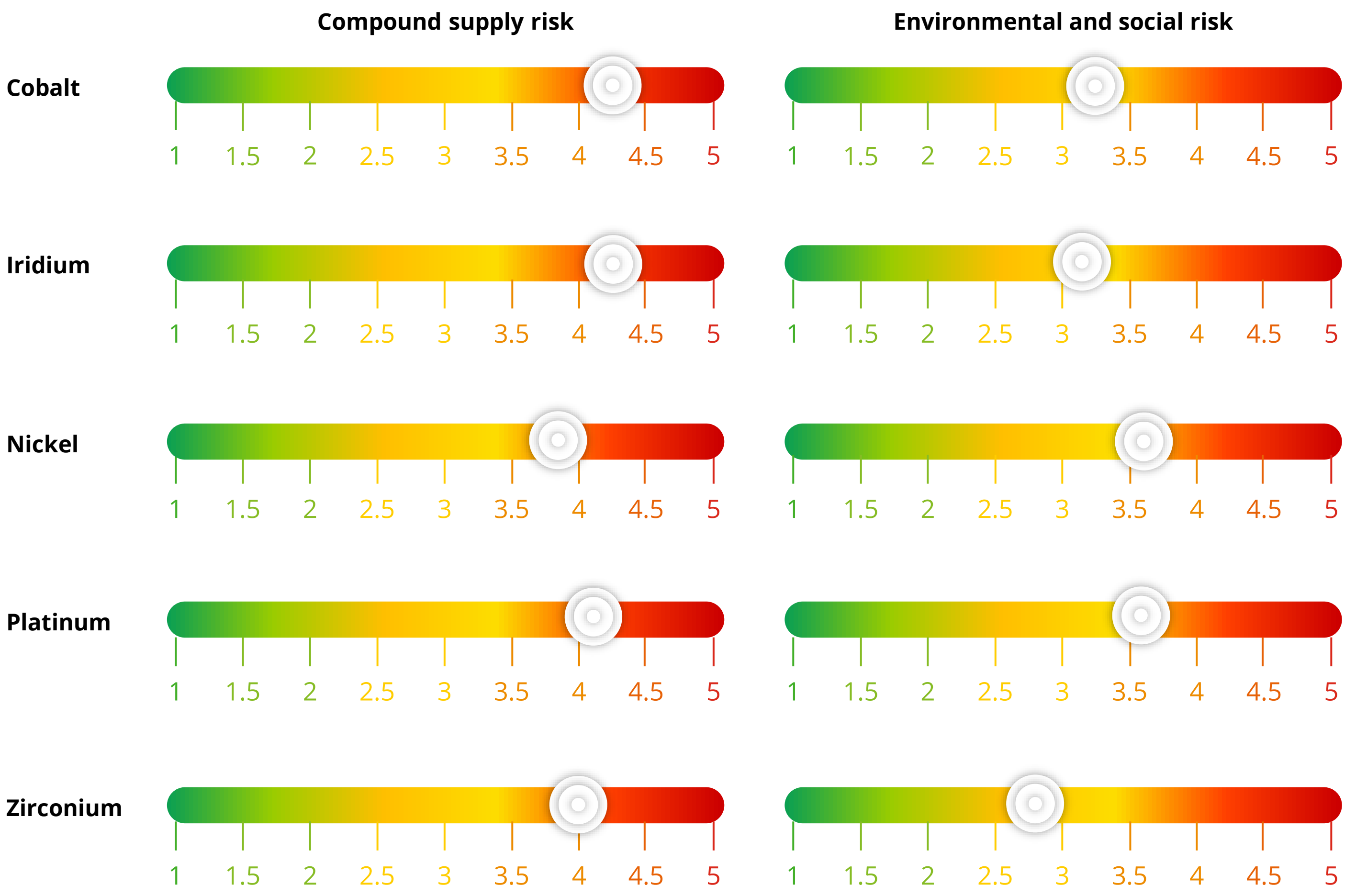
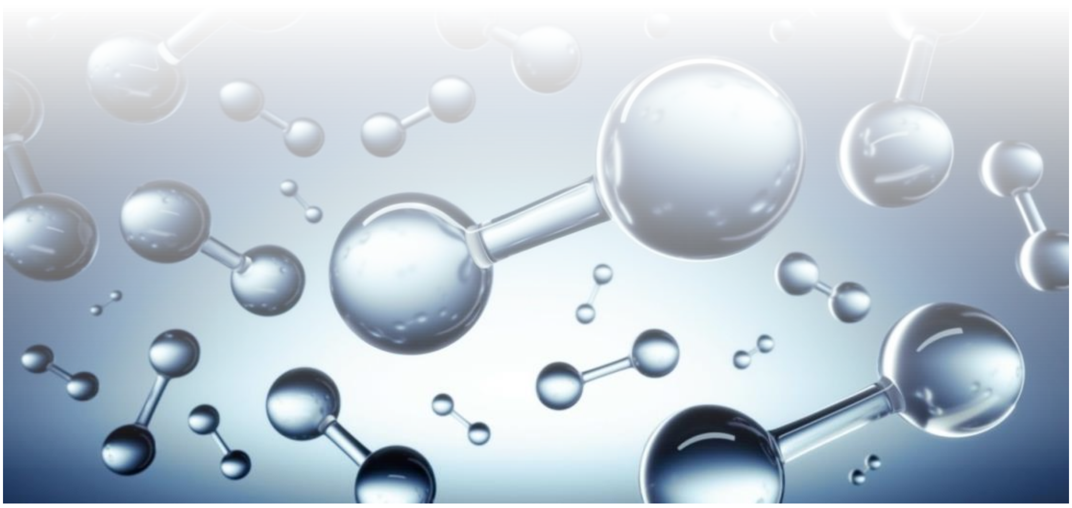


Figure 19: Hydrogen energy sector dependencies

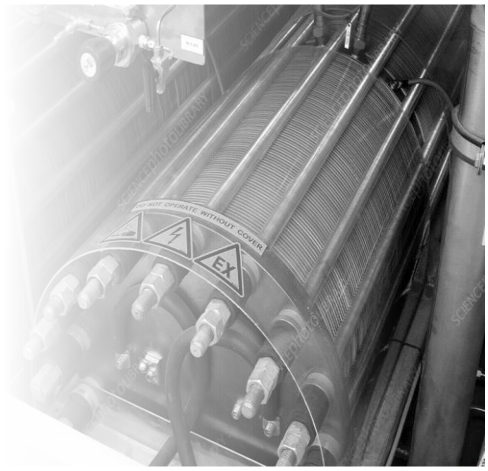


Key findings

Range of electrolysers support hydrogen production with different CRMs needed depending on approach

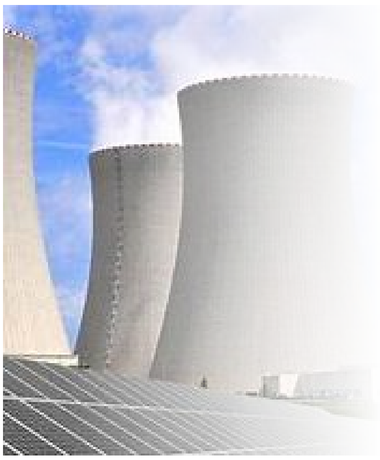
Electrolysers are a technology that is key to the production of hydrogen. There are three main types of hydrogen electrolysers: proton exchange membrane (PEM), solid-oxide electrolysis cell (SOEC), and alkaline electrolysis (AE). While PEM electrolysers are made using iridium and platinum, SOEC and AE electrolysers are made with a nickel and zirconium base,[234] meaning that CRM dependencies vary significantly according to the technology used.

PEM electrolysers are currently seen as the most effective technology for green hydrogen production, given their strong performance when connected to intermittent energy sources, such as renewables.[235] They are able to produce the high purity of hydrogen needed for HFCs and can operate at low temperatures with high efficiency. However, their dependency on iridium as an anode material means there could be a significant shortage risk when looking to scale the technology at current iridium loadings, with only 7.5 tonnes mined annually.[236] The majority of iridium is mined as a minor by-product of platinum – produced primarily in South Africa[237] – which makes increasing iridium production challenging. This means that the long-term viability of PEM electrolysers will depend on efficiency, by designing with lower quantities of iridium while also pushing for broader efficiency gains in the technology, both of which are subject to intensive R&D efforts that are already bearing fruit.[238]



There is also potential for increased iridium availability due to improved recycling rates. For example, significant quantities of iridium are used annually for spark plug ignition tips in gasoline vehicles, which are not generally recovered from vehicles when scrapped. The UK does have a competitive advantage in this space, with developed PGM supply chains, infrastructure, and expertise.

By contrast, SOEC and AE electrolyser technologies are less effective at producing green hydrogen. For example, SOECs require significant energy inputs as they operate at 500-85 degrees Celsius, while AEs have much lower energy efficiency,[239] impacting total output. It is therefore likely that iridium will remain a core CRM dependency for green hydrogen production.

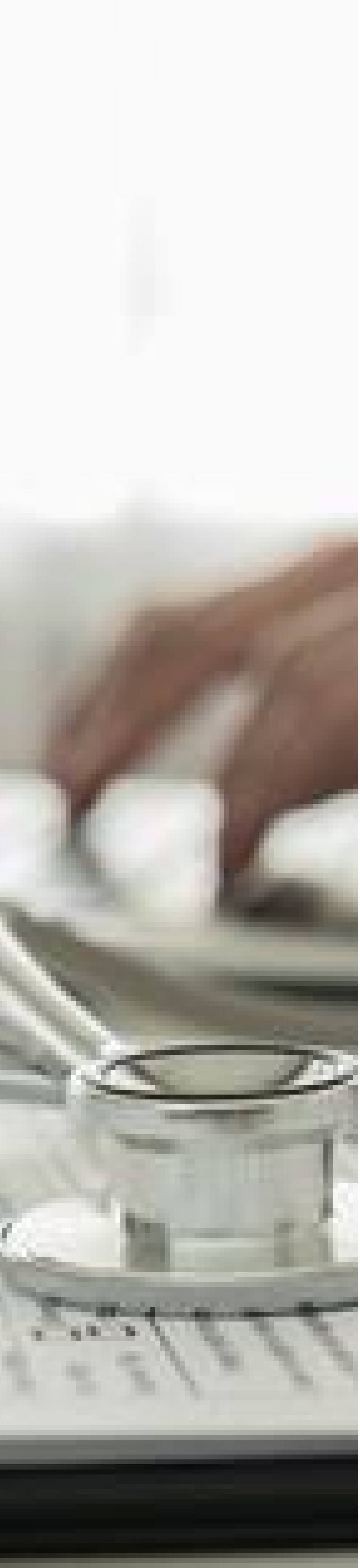


Hydrogen fuel cells use cases continue to be developed through new R&D

The use-case for HFCs in the automotive sector was discussed earlier in this report and there are a range of other potential applications for this technology (although efficiency constraints render them currently unviable). Included in these potential applications are commercial and residential heating, electricity generation for the grid, and backup power generation.[240] As with electrolysers, the minerals and metals used in HFCs depend on the technology and design, although all comprise three functional components: an anode, a cathode, and an electrolyte.[241] Metals commonly used in these components can include PGMs, nickel, tantalum, titanium, graphite, and zirconium, as well as a corrosion resistant ceramic,[242] which may itself also require CRMs.

The ongoing R&D into these technologies means that dependencies and volumes are likely to evolve over time, so companies will need to remain alert to the changing needs of the sector as it seeks to expand in the future. For example, Bramble Energy, a spinout of Imperial College and University College London, claims that their printed circuit board (PCB) technology, which uses more cost effective conductive and dielectric materials, could pave the way to lower HFCs in the future.[243] Full testing is expected in April 2024.

234 IEA, "Estimated levelized demand for selected minerals in electrolysers and fuel cells today, log scale," International Energy Agency, May 5, 2021.
235 Shiva Kumar and Himabindu, "Hydrogen production by PEM water electrolysis – A review," Materials Science for Energy Technologies, December 2019.
236 Task & Finish Group Workshop, October – November, 2023.
237 Peter Hobson, "Tight supply and hydrogen hopes drive iridium up 160%," Reuters, February 12, 2021.
238 Task & Finish Group Workshop, October – November, 2023.
239 ibid.
240 Ian Staffell et al., "The role of hydrogen and fuel cells in the global energy system," Energy & Environmental Science, 2019.
241 Yousaf Shah et al., "Toward next-generation fuel cell materials," iScience, May 16, 2023.
242 Department of Chemical Engineering and Biotechnology, "Types of Fuel Cells," University of Cambridge, Accessed October-November, 2023.
243 Bramble Energy, "System Architecture Advantages of the PCBFC," Accessed October-November, 2023.



Sector Risk Assessment: MedTech

Foreword

The manufacture of medical technologies is increasingly a global process. Consequently, critical minerals are usually imported into the UK as part of finished products or as components which are then incorporated into devices. It is therefore difficult to estimate the extent of the UK criticality with respect to raw materials in this sector.

Having said this, the sector does 'technically' rely on critical minerals, from lithium containing batteries to the use of REE in touch-screen interfaces.

Two areas of concern for ABHI members, however, were with regards to the provision of tungsten, which is used extensively in the manufacturing of dental products, such as drill bits, and of phosphate materials, which are used in orthopaedics as joint space packing materials. Indeed, with respect to tungsten, the UK is home to one of the largest manufacturers of dental drill bits.

A potential issue was highlighted, albeit outside of the ABHI's remit of medical technologies, for the supply of bismuth, which is used as a radio-opaque material in certain radiography applications. Full information on this could not be obtained.

Consideration was given also to recovery processes, for example with REE within stainless steels used for surgical instruments. In these instances, manufacturers use specified collection and recycling companies, experience of which suggests that little knowledge exists as to the presence of critical elements. It is unlikely therefore, that any recovery of critical minerals takes place within these groups.

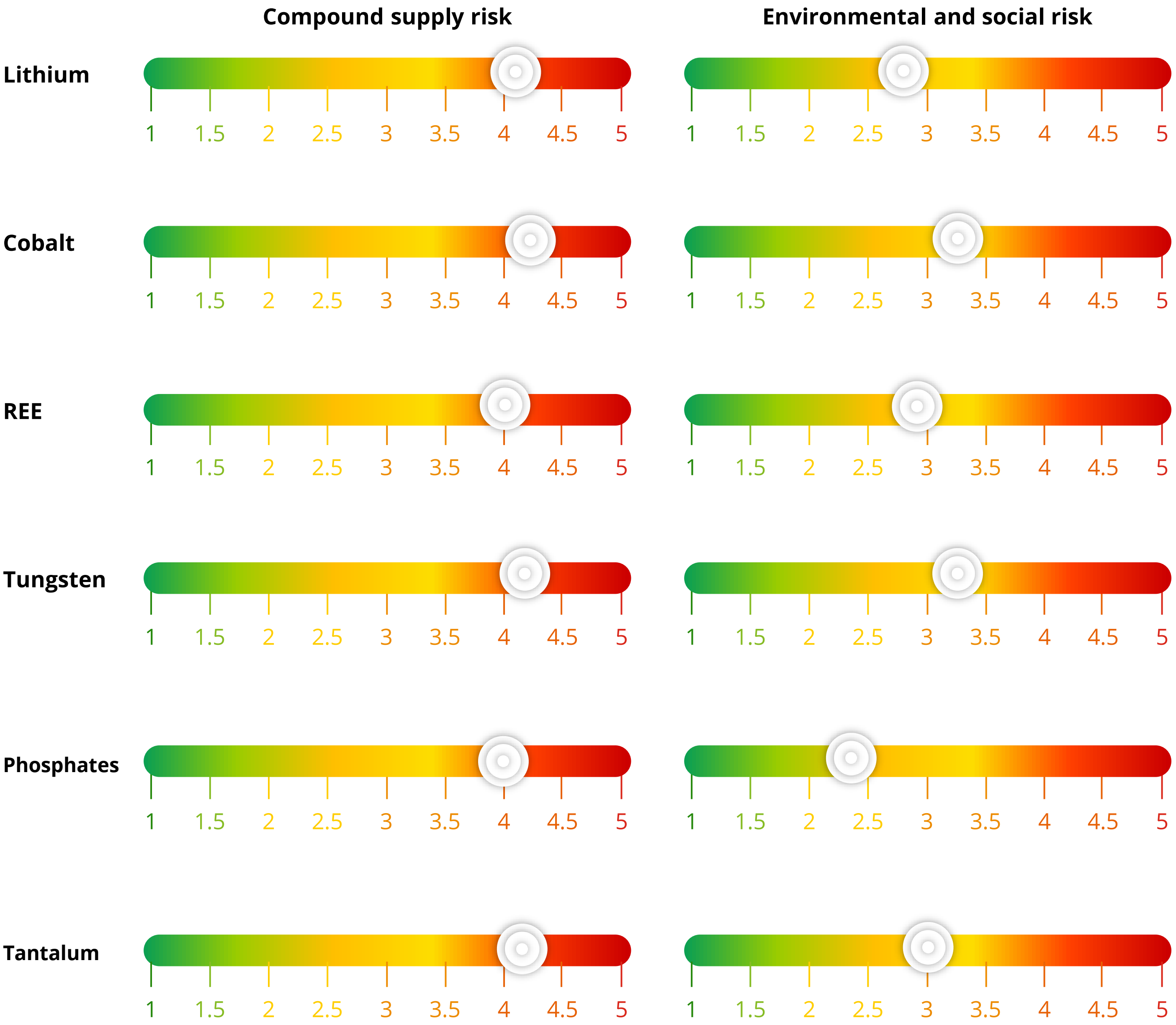
Phil Brown
Director Regulatory & Compliance at ABHI

Introduction

The UK MedTech industry, which consists of 4,190 businesses, has an annual turnover of £27.6 billion and exports over £5 billion of products annually.[244] MedTech supply chains are often intricate, spanning multiple stages and countries. Owing to the wide range of products and services in the sector, it is challenging to compile an exhaustive list of all materials that are crucial to the industry.[245] Nevertheless, T&F Group members from the MedTech sector identified a series of CRM dependencies used to produce key materials essential for medical devices, such as apparatus, imaging technologies, or implants. Figure 20 below illustrates some of these dependencies and their associated risk ratings, based on the risk assessment.

Risk framework findings

This report uses a quantitative risk matrix to highlight the CRMs which pose the greatest risk to each industry (see methodology section). Figure 20 summarises the top nine CRMs for the MedTech sector by overall supply risk (compound supply risk). The supply risk is calculated by multiplying the impact of a disruption to supply (material importance) by the likelihood of a disruption to supply (supply risk). In addition, the below table shows the ESG risk associated with each CRM that demonstrates the impact the material has on the environment and society.



[244] Department of Health & Social Care, "Medical Technology Strategy," UK Government, February 3, 2023.
[245] Office for Life Sciences et al., "Bioscience and health technology sector statistics 2020," UK Government, December 7, 2021.

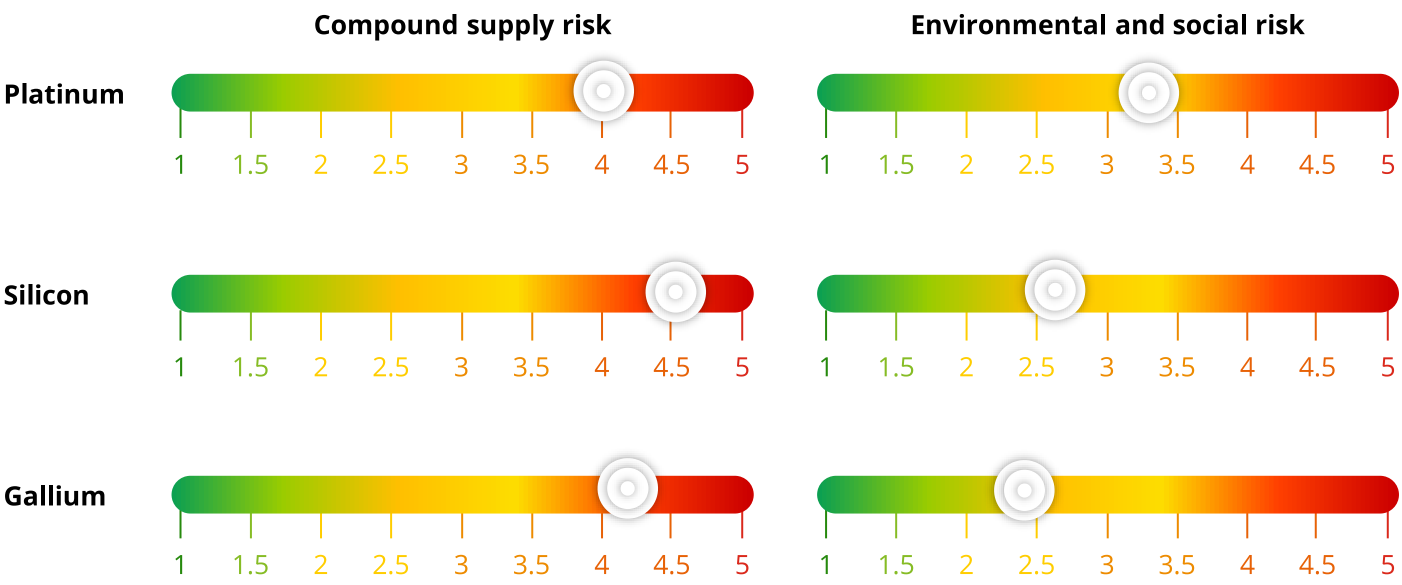


Figure 20: MedTech sector dependencies

Risk register

The risk register below outlines the top three supply risks to the MedTech sector based on analysis of quantitative and qualitative data, including the risk assessment and T&F Group member interviews. It is important to note that the risk register selected risks based on the highest score derived from the supply risk aspect of the methodology framework. ESG risks were evaluated per mineral, not per sector, hence their exclusion from the risk register and inclusion in the earlier section. For further information on ESG risks, please refer to the environmental and social risk section on page 20.

Risk type	CRMs impacted	Risk description
Import reliance	lithium, cobalt, REEs, tungsten, gallium, platinum, tantalum	Import reliance in the MedTech sector can lead to supply chain vulnerabilities, quality, and safety risks, and can limit innovation and growth. Disruptions in the production or delivery of CRMs can cause delays, increased costs, and reduced competitiveness. Lack of control over the quality and safety of imported materials can pose risks to patient safety and regulatory compliance. Heavy reliance on imported materials can also discourage investment in research and development, putting the industry at a disadvantage compared to countries with more diversified supply chains.
Mining concentration	lithium, cobalt, REEs, tungsten, gallium, platinum, phosphates, silicon	High mining concentration can lead to a lack of control over the quality and sustainability of the mined materials. This can pose risks to the environment, human health, and regulatory compliance, particularly if the mining practices do not meet the required standards. Additionally, it has significant environmental impacts such as deforestation, soil erosion, and water pollution, which can have long-term consequences for communities and ecosystems.
Processing stage concentration	lithium, cobalt, tungsten, gallium, platinum, REEs, silicon	High processing concentration can limit diversification opportunities for mid-stream companies, which can have significant downstream effects in the event of supply disruptions. In the MedTech sector, this can result in shortages of key components if there is a disruption in processing activity, ultimately affecting the availability of key medical devices and equipment. Such disruptions can create severe impacts on patient care and outcomes, particularly in emergency situations where timely access to medical devices and equipment is critical.

Figure 21: MedTech supply risk register

Key findings

REEs needed across a range of medical imaging products with supplies from China dominating

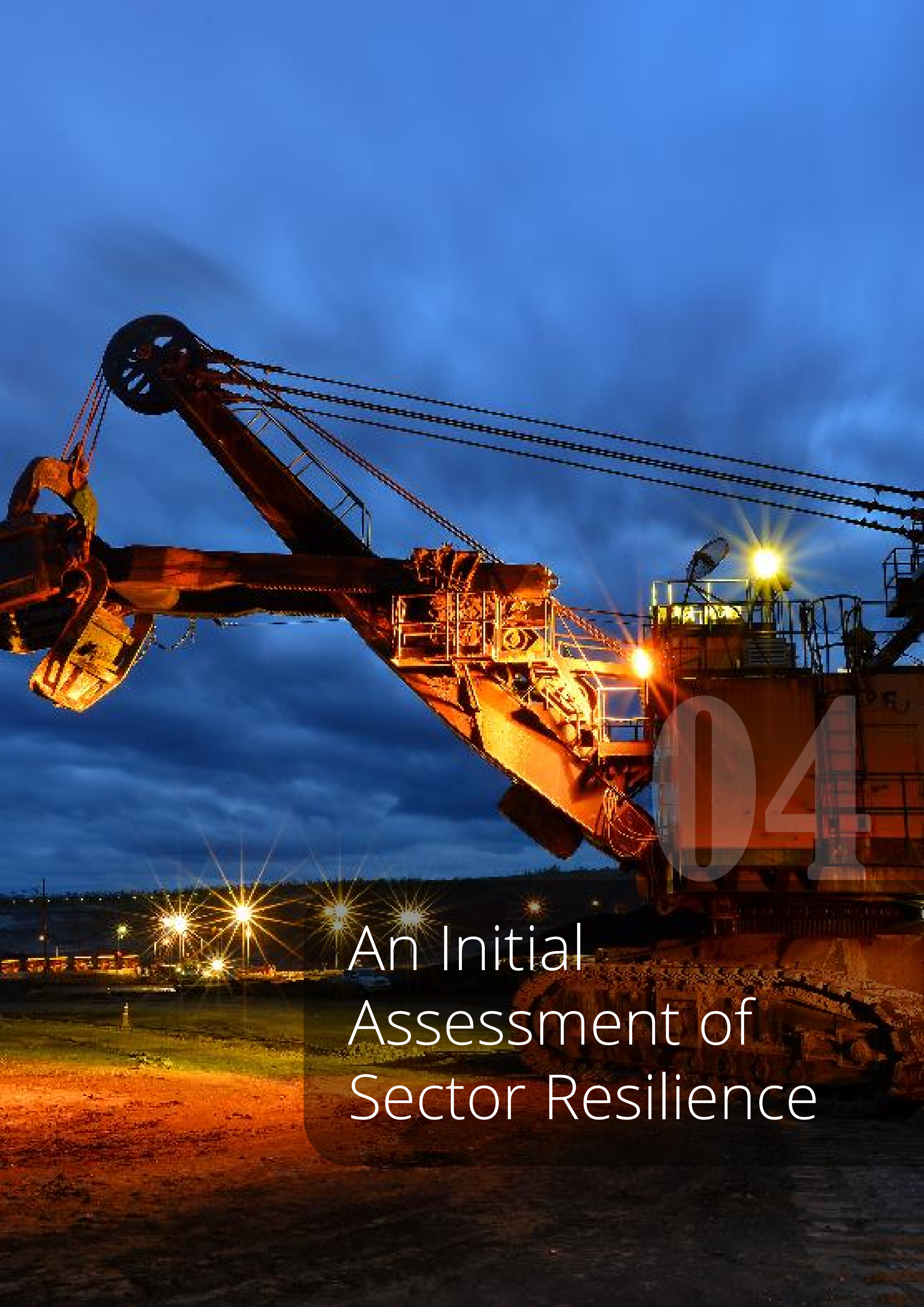
The MedTech industry relies on REEs for medical imaging purposes, such as MRIs. REEs are extensively used in medical technology, with gadolinium-based compounds serving as a contrast agent to image tumours with MRI, which itself uses REE magnets.[246] Additionally, REE magnets are used in MRI machines to generate the magnetic field required for imaging. Other medical devices that use REEs include X-ray tubes, computed tomography (CT) scanners, and ultrasound machines.[247] As previously established, 96% of REEs are imported from China, highlighting a national concern of over-reliance on imports from a single country, which could leave the MedTech industry exposed to REE supply chain shocks.

Semiconductors demand is across industries with supply constraints heavily impacting the MedTech sector

Semiconductors play a crucial role in the MedTech industry, being widely used in medical imaging, patient monitoring, and diagnostic equipment, including blood glucose monitors, ECG machines, and pulse oximeters.[248] These devices rely on semiconductors to process and analyse data, control operations, and communicate with other devices. As semiconductors are an essential component of all electronic medical devices and in vitro diagnostics, their shortage is relevant to a vast number of healthcare services.[249] We have included more information on semiconductors in the electronic section.

Owing to a lower priority of CRM supply chains in the MedTech industry, it has been challenging to gather the same level of insights as in previous sections. The industry has been primarily focused on recovering from supply chain disruptions caused by the Covid-19 pandemic, particularly in response to the global shortage of PPE equipment.[250] The pandemic highlighted production vulnerabilities, with a significant increase in demand for PPE resulting in an additional £15 billion in expenditure.[251]

[246] Intertek, "Rare Earth Elements," Accessed October-November 2023.
[247] Sierra Hovet et al., "MRI-powered biomedical devices," Minimally Invasive Therapy & Allied Technologies, May 7, 2019.
[248] MedTech Europe, "Global Semiconductor Shortage Need for Prioritisation of Healthcare Capabilities," July 26, 2022.
[249] ibid.
[250] Fiona Miller et al., "Vulnerability of the medical product supply chain: the wake-up call of COVID-19," BMJ Quality & Safety, 2021.
[251] Evolve UK, "Medtech manufacturing in the UK," 2020.



04 An Initial Assessment of Sector Resilience

An Initial Assessment of Sector Resilience

This report focuses on the impact of mining and processing on the six sectors highlighted in the previous section, surfacing risks at the material level. For many UK companies, these risks tend to be beyond their tier one suppliers, given the fact that procurement, in most cases, either happens after mid-stream processing, or relates to a series of component parts, rather than the raw materials themselves.

This section of the report aims to provide a high-level assessment of UK industry maturity against sector resilience measures, and is primarily based on industry questionnaires, interviews, and workshops. It is considered an initial assessment as it does not necessarily constitute a representative sample of UK industry; rather, it aims to summarise broad trends, best practices and key risks across different areas related to this report. To highlight the key elements of companies' policies and strategies, this report will group these efforts into two broader categories: material traceability and supply chain transparency; and closing value chain loops through building a circular economy. These will be addressed after first sharing findings on the broader state of industry supply chain resilience and sustainability strategies.

Based on the initial assessment for this report, the larger and more mature companies in the UK have in recent years been developing approaches to enhance supply chain resilience across the two areas highlighted above. These strategies and policies aim to help organisations set coherent and integrated objectives across a company and support resilience within procurement and supply chain operations teams. The same is true of sustainability strategies, which companies are increasingly adopting, particularly across procurement and sourcing with increased expectations of suppliers. Despite having resilience and sustainability policies in place, however, questionnaire and interview respondents pointed to challenges with regards to implementation of policies.

Resilience policies and strategies tend to differ and are often also driven by reporting requirements and regulation.[252] Though industry participants highlighted that they welcome regulation, they also pointed to the lack of consistency in reporting and regulatory requirements across markets, something which impacts the level playing field. Due to existing reporting requirements around supply chain due diligence, modern slavery and forced labour, companies are often further along with understanding their impact around these factors than with their environmental and material footprints. On environmental risks, while companies increasingly have a strong understanding of their carbon emissions, non-carbon impacts (e.g., water stress, biodiversity) tend to get less attention than carbon.[253] In addition, few companies have engaged in modelling or testing the impact of supply chain disruption within these strategies.

Depending on where a company operates in the supply chain, their approach to CRMs may vary significantly. For example, it is common for manufacturing companies to have policies whilst at the same time being completely removed from the actual procurement of CRMs. There is a flow-down of requirements, but these become opaque and almost impossible to audit. Therefore, the ability for UK manufacturers to verify true compliance with policies remains a prominent risk.[254] Companies are also increasingly focusing on recycling and recovery of materials in their strategies and policies, driven by material and sector-specific regulation – something that will be covered in further detail in the circular economy section of this chapter.

Competing business risks also complicate the CRM resilience picture. For example, the higher cost of borrowing has led to some companies reducing their material stock holding to a bare minimum, especially close to the end of a fiscal period to help support their cash metrics when reporting to shareholders.[255] According to respondents, supply chain disruptions linked to the semiconductor shortage and Covid-19 pandemic have elevated the importance of supply chain transparency across all sectors, meaning that companies have aimed to increase supply chain resilience post-2020.

However, there is a widely held view that companies are not yet comfortable with their level of supplier oversight and diversification, and that this presents significant risk in building resilient CRM supply chains. In addition, the overreliance on geographies like China remains an ongoing challenge, particularly in CRM supply chains, with few viable alternatives on the necessary scale in the foreseeable future.[256] In line with this, respondents indicated more interest from the boardroom in mapping and diversifying supply and conducting continuity of supply assessments.[257]

[252] Task & Finish Group Workshop, October – November, 2023.
[253] ibid.
[254] ibid.
[255] ibid.
[256] ibid.
[257] ibid.

Supply chain transparency

Industry stakeholders indicated a strong cross-sector understanding of the benefits associated with material traceability, supply chain transparency and understanding and monitoring supply chain risks. However, the implementation of measures that support these is less developed, and the complexity of supply chains is a major challenge for improving transparency. Alongside complexities of understanding the supply chain, industry stakeholders highlighted the role of commercial sensitivities restricting the ability of supplier disclosure even for UK trade companies, let alone foreign producers.[258]

According to questionnaire and interview respondents, many UK companies are procuring component parts rather than specific CRMs, which leads to a challenge obtaining supply chain data and they don't have the look through to the CRM themselves. This challenge is more pronounced as getting this insight would require engagement with suppliers beyond tier one, with a stronger focus on mining and processing stages. Through questionnaires and interviews, respondents pointed to greater oversight in the energy sector over the automotive sector across the supply chain.[259] While specific reasons were not provided, this could potentially be linked to the nature of energy project contracts and their requirements, which do not necessarily exist in the automotive sector. Nevertheless, with upcoming regulation on batteries and due diligence in geographies like the EU, enhanced oversight is expected in the automotive sector as well. While efforts to be made to ensure better compliance, these efforts should not restrict supply or be counter-productive to supply.

According to questionnaire and interview respondents, the utilisation of traceability technologies, which may include blockchain solutions, is limited at present, although most sector representatives surveyed indicated that they were exploring opportunities to invest in enhanced traceability solutions to monitor value chains with the highest risk or due to upcoming regulatory requirements.

While respondents highlighted the need and intention to utilise traceability solutions, they similarly pointed to the challenges utilising traceability tools across supply chains, pointing to interoperability and noting that specific CRMs and supply chains may require a different suite of tools to measure, based on intention and purpose of traceability.[260]

[258] Task & Finish Group Workshop, October – November, 2023.
[259] ibid.
[260] ibid.

Circular economy

The uptake of practices related to the circular economy are starting to become more commonplace and are emerging across industry. While sectors are still learning how to implement circular value chains and companies try to work out their respective roles in the model, there was broad consensus amongst respondents that CRM circularity represents a strong opportunity to improve supply chain resilience and sustainability.

Despite the interest in circular economy solutions, interviewees and respondents pointed to several barriers to scaling the circular economy. One respondent pointed to the lack of working capital required for effective recycling of expensive metals.[261] Others pointed to challenges relating to the recovery of products at end-of-life, as well as the challenges facing circular business models focused on products-as-a-service and increasing effective recycling.

Respondents also pointed to the specialised recycling processes required to effectively recover CRMs. For example, if the REE in wind turbines end up in a standard metal recycling facility they will not be captured due to their magnetic properties. In addition, because recycling processes are still too often based on shredding, many CRMs are still difficult to recover. Similarly, in the electronics sector, the REE content is so small on a per product basis that significant aggregation is needed to reach the economic viability of using specialist recycling facilities for recovery.

PGMs present a unique circularity profile among CRMs, requiring mature recycling practices and infrastructure. The UK hosts the world's largest secondary refiner (recycler) of PGMs by volume, with its large UK-based operation serving a global market. It is therefore reliant on cross-border movements of end-of-life material and refined product, demonstrating the importance of effective reverse supply chains. PGM recycling is well-established because it is value-driven: the value of the PGM is usually sufficient to incentivise collection and secondary processing. The fact that primary (virgin) and secondary (recycled) PGMs are completely fungible with no difference in properties supports this. But, even for PGMs, scope exists to boost collection rates in several applications through appropriate measures, such as mandated producer responsibility. The UK would be positioned to leverage its PGM infrastructure and benefit from such measures globally if policymaking and trade agreements are supportive.

Another challenge that surfaced from interviewees related to international standards pertaining to the definition of waste and the regulation of cross-border movement of products at end-of-life. The Basel Convention plays a vital role in stopping the illegal dumping of waste. However, companies identified that it can also impede the development of international reverse supply chains for products at end-of-life.[262 263] Alongside this, an adequate enforcement regime for the treaty is also key, to properly regulate shipments that can be easily misdescribed and sent abroad.[264]

As circular economy requires both interventions at the end of the value chain and at the start, companies are starting to consider circular design principles, particularly in areas like electronics.[265] In sectors with specific contract and procurement requirements, such as aerospace and defence and chemicals, circular design principles are harder to implement. With regards to developing closed loop systems, there is an opportunity to expand business opportunities around larger pieces of capital equipment. For example, there are opportunities to recover wind turbines upon decommissioning. Developments in the traceability and product passports space (e.g. battery passports), explored in the previous section of this chapter, could be a mechanism to further enable effective recycling and recovery of materials.

With circular product design, companies did point to the emergence of demand reduction strategies, a key principle of circular economy. This includes methods like reduction of cobalt demand, thrifting for platinum or reducing the quantity of iridium in electrolysers. While companies pointed to the need to address some of these challenges, the lack of a concrete business case and investment makes this more challenging to implement.

261 Task & Finish Group Workshop, October – November, 2023.
262 World Economic Forum, "Facilitating Trade Along Circular Value Chains," September, 2020.
263 Task & Finish Group Workshop, October – November, 2023.
264 ibid.
265 ibid.

Sector-specific resilience measures

Sector-specific trends are also apparent amongst T&F Group members. The automotive sector has started to look towards vertical integration – the ownership/partnership of companies within supply chains – to secure supply of battery metals, such as lithium and nickel. While this is still in its infancy, vertical integration will likely grow as an automotive strategy in the coming years and represents a very strong form of resilience building.

In the aerospace and defence sector, the pandemic made stockpiling more common, with companies trying to protect operations against supply chain disruption. Whilst the level of stockpiling depends on the volume and criticality of a mineral or metal, it is often equivalent to 3-6 months' supply, providing moderate protection against any short-term supply chain disruption. The ability to stockpile in one sector may not, however, be appropriate for others, where stockpiling may limit global progress, such as in the energy sector with the CRMs needed for the transition. In addition, financial barriers may restrict industry from stockpiling appropriately, putting industry at risk.

The chemicals sector stressed the importance of supplier diversification for building resilience. Chemical companies face high operational risk from shortages of any input, and so have developed advanced, highly diversified supplier networks to help ensure continuity of supply. Meanwhile, in the energy sector, some businesses have started to engage more directly with suppliers to build relationships. Long-term, healthy relationships with suppliers can help them understand input needs and reduce the risk of delivery delays.

Priorities in the electronics and MedTech sectors are slightly different owing to the semiconductor shortages and Covid-19 pandemic. While the electronics sector has started to introduce some measures to bolster CRM resilience, such as using interchangeable parts in products, over the last two years, efforts have been focused on securing semiconductor supplies. Likewise, MedTech companies have primarily been focused on maintaining the supply of products like PPE and syringes, and so have been slower to establish clear resilience measures for CRMs.

Other key insights on resilience measures

Substitutability

T&F members expressed that minerals and metals are selected for specific applications based on the suitability of their properties. As such, alternative materials cannot simply be used for these applications without compromising performance. Substitutability is therefore currently not a solution to CRM risk and needs to be considered through a sectoral lens given specific applications.

However, this picture changes in the long-term, as testing is done on alternative materials in product design to reduce dependencies on high-risk materials and new manufacturing processes can be assessed. Changes in manufacturing processes in the priority sectors for this report are subject to significant long term investment horizons and regulatory oversight, resulting in limited short-term changes. There is also a strong role for research and development with early-stage government support.

CRM form

UK industry sectors require minerals and metals in different forms based on their stage in the supply chain. For example, midstream OEMs tend to have a greater dependence on processed materials, while downstream manufacturers often rely more on components and complex alloys. This means that the UK's CRM dependencies are not limited to minerals and metals, but also the components and materials that they are embedded within. It also highlights that, from an opportunity perspective for the UK, some aspects of the value chain are easier to build on, in particular where there are existing capabilities.

05

Future trends

Future Trends

The demand and supply of CRMs globally is changing rapidly. These changes and trends are an important factor in understanding risk and resilience. While the rest of this report has been based on data and interviews, this analysis uses secondary research to examine possible future trends in CRMs markets, risks, and vulnerabilities at both a global and UK level. The analysis was conducted using a three-pronged approach:

- Researching supply and demand trends using cross-sector and sector-specific databases to map out major trends in forecasted supply and demand of CRMs under a net-zero scenario;
- Ascertaining how the UK's planned investment in mining, refining, and recycling infrastructure will impact CRM risks through onshoring supply chains; and
- Exploring the UK's agreements and partnerships, alongside trade partners' agreements and partnerships, which provides insight into the strategies employed by different countries to secure CRM supplies.

Supply and demand trends[266]

An analysis of supply and demand trends was conducted for the top ten cross-cutting sector dependencies identified in the risk assessment section of this report. The objective of this analysis is to assess future CRMs demand and supply, including potential shortfalls, and provide commentary on what this could mean for specific sectors. The ten cross-cutting sector dependencies reviewed in this section are:[267]

Lithium	**PGMs[268]**
Copper	**Silicon**
Cobalt	**Gallium**
Nickel	**Tantalum**
REEs	**Titanium**

[266] A caveat of the data collection process is that there is limited availability for supply and demand projections in the MedTech, Chemicals and Electronics sector. Additionally, a specific UK view on supply and demand was not feasible, as much of this data does not yet exist; much of the UK focused data reflects specific mineral usage, rather than from a macro perspective.

[267] These minerals were selected as cross-sector dependencies for UK industry, but also due to availability of secondary data and sources, although availability varies for different CRMs. Primary data modelling was out of the scope of this analysis but will be better covered in forthcoming publications by CMIC. A key source is the International Energy Agency's (IEA) body of work on CRMs, figures from IEA sources use the net-zero scenario (unless otherwise stated). This scenario was selected given the UK and global commitment to meeting the Paris Agreement and the UK's commitment to reaching net-zero by 2050. This analysis does not draw distinctions between the form of CRM.

[268] PGMs analysed in place of platinum owing to data availability.

Lithium

Driven by the transition to EVs, the global demand for battery technologies is anticipated to lead to an increase in global lithium demand from 130 kt in 2023 to 721 kt in 2030 and rising to 1,313 kt in 2050 (80% of which will be for the automotive sector).[269] As a result, there are concerns of a global lithium shortage by 2025.[270] It is forecast that there will be around 8 to 11 million electric cars sold in the UK by 2030, increasing to 25.5 million by 2040.[271] Estimates of what this means for UK lithium demand vary, but it is likely that the UK will require between 50,000[272] to 64,000 tonnes[273] of lithium per year by 2030 onwards for EVs alone in response to growing demand.[274] Other non-automotive uses of lithium will mean that the true figure will be higher, although EVs will be the main source of demand, followed by BESS.

While the world's lithium reserves are theoretically sufficient to meet demand, one of the key challenges on the supply side is developing and scaling new mining projects to exploit these resources, as well as establishing capacity to process it.[275] Currently five companies are responsible for 75% of global lithium chemical production.[276]

Copper

Global copper demand is expected to grow from 25,500 kt in 2023 to 35,613 kt in 2030 and 39,733 kt by 2050, by which time nearly half all demand will be from clean energy technologies, such as expanded electricity networks, EVs, and wind turbines.[277] Over 250 mines spanning across 40 countries are currently in operation, with copper production output reaching 21 kt. However, production at many major copper mines has peaked owing to declining ore quality and reserve exhaustion.[278] The potential supply deficits which could emerge because of this will be partially offset using alternative materials in certain applications, such as PVC in piping, although the broad cross-sector applications could still lead to a supply shortfall.

Cobalt

Global cobalt demand is projected to increase three-fold, from 171 kt in 2023 to 520 kt in 2050, following a 70% increase in demand from 2017 to 2022.[279] Roughly half of this projected growth is driven by EV demand, although other major uses include superalloys. In the UK, projected demand varies based on scenario – for example, the mix between NMC and LFP batteries in future gigafactories – but could be up to 11.2 kt by 2030.[280] When considering the supply of cobalt, the biggest challenge is not the availability of resource, but the economic feasibility of mining and refining to meet the specifications required for EVs in the necessary quantities by 2030.[281] Demand growth in cobalt is expected to broadly level off after 2035 as new (lower cobalt) battery chemistries are scaled and an increase in circularity lowers the demand for virgin cobalt.

[269] IEA, "Critical Minerals Data Explorer," International Energy Agency, July 11, 2023.
[270] World Bank.
[271] IEA, "Critical Minerals Data Explorer," International Energy Agency, July 11, 2023.
[272] Local Government Association, "Electric vehicles: What's going on out there?" Accessed October-November, 2023.
[273] Advanced Propulsion Centre Q2 demand forecasts.
[274] Steve Massey, "Why does the UK need a Lithium Supply Chain?," HSSMI, May 4, 2022.
[275] T&F Group Member Interview October-November, 2023.
[276] Lithium supply and demand trends (World Economic Forum).
[277] IEA, "Critical Minerals Market Review 2023," International Energy Agency, July, 2023.
[278] IEA, "The Role of Critical Minerals in Clean Energy Transitions," International Energy Agency, May, 2021.
[279] IEA, "Critical Minerals Market Review 2023," International Energy Agency, July, 2023.
[280] Paul Lusty et al., "Study on future UK demand and supply of lithium, nickel, cobalt, manganese and graphite for electric vehicle batteries," British Geological Survey, July 4, 2023.
[281] IEA, "Critical Minerals Market Review 2023," International Energy Agency, July, 2023.

Nickel

Global nickel demand is projected to increase by almost 50% by 2033, with a rise from 2,900 kt in 2023 to more than 5,800 kt by 2033[282] and to 6,200 kt by 2050.[283] This increase is attributed to rising demand for EV batteries, with demand for other uses, such as alloying applications, remaining relatively constant. Meanwhile, global nickel supply is expected to increase from 3,400 kt in 2023 to 4,400 kt by 2033, failing to meet demand levels.[284] In many NMC battery chemistries, such as NMC-622 and NMC-955, nickel comprises the biggest proportion of cathode active materials (CAM)[285] meaning any shortfall in supply could inhibit future EV production.

REE

The demand for REEs, particularly neodymium, dysprosium, praseodymium, and terbium, is increasing due to the growing use of permanent magnets in clean energy technologies. Neodymium is expected to see its demand double by 2030 with demand steadying at just over 100 kt per year from 2030 onwards.[286] In the automotive and energy sectors, this projected growth is a result of increased demand for the permanent magnets used in EV electric motors and wind turbine generators. However, uses of REEs in electronics applications will also drive demand to a degree.

Silicon

Demand for silicon in the automotive and energy sectors is projected to triple from a 2022 baseline of 842 kt per year to around 2.5 Mt per year by 2030, and then peak at over 2.6 Mt per year by 2035.[287] This growth will be driven primarily by the demand for crystalline silicon solar cells in the years up to 2030, and then increasingly by silicon doping in EV batteries post-2035. From a supply perspective, silicon is the second most abundant element in the earth's crust,[288] meaning that potential for increased resource extraction is not a constraint. However, processing capacity will have to keep pace with demand to prevent supply deficits in the future.

282 Project Blue.
283 IEA, "Critical Minerals Market Review 2023," International Energy Agency, July 2023.
284 Project Blue.
285 Paul Lusty et al., "Study on future UK demand and supply of lithium, nickel, cobalt, manganese and graphite for electric vehicle batteries," British Geological Survey, July 4, 2023.
286 IEA, "The Role of Critical Minerals in Clean Energy Transitions," International Energy Agency, May 2021.
287 IEA, "Critical Minerals Data Explorer," International Energy Agency, July 11, 2023.
288 Greenwood & Earshaw, "9- Silicon", Chemistry of the Elements, 1997.

PGMs

Unlike other CRMs, where future demand is projected to outstrip supply, there is a risk in PGM markets that demand for certain metals may be insufficient to maintain supply levels in the future.[289] PGMs occur and are mined together, and their current biggest demand driver is catalytic converters, for which 377 tonnes were used in a 2019 (peak demand).[290] However, while platinum and iridium will be key to produce hydrogen technologies such as HFCs and electrolysers, the uses of palladium, rhodium, ruthenium and osmium are far less clear, as catalytic convertor demand begins to fall. This could create supply challenges for platinum and iridium, since all six PGMs are mined together, and the financial viability of mining operations could be severely impacted by a fall in value for palladium, rhodium, ruthenium, and osmium. In turn, this could impact the scaling of HFCs and electrolysers.

Gallium

Gallium demand for use in solar cells is projected to increase moderately by 2040. The current baseline is unclear in IEA data, but by 2040 it is expected that 5.53 kt per year will be used in solar photovoltaic. This will then subside to around 5 kt per year by 2050.[291] This increase will be driven by gallium doping for silicon solar cells, and the scaling of copper indium gallium selenide solar cells (CIGS) production. While this is dwarfed by forecasts for silicon photovoltaics, the overall demand for gallium will likely be far greater, owing to its variety of other key uses, such as semiconductors and electronic devices. However, there is limited data availability in this space.

Tantalum

Global demand for tantalum is projected to reach 4.5 kt by 2030, up from 2.4 kt in 2022.[292] The main driver of this growth will be its use in capacitors and engine turbine blades, as the electronics and aerospace and defence sectors continue to be the biggest consumers. However, its use in low emissions power generation is also projected to increase, growing from 0.04 kt in 2022 to 0.4 kt by 2030.[293]

Titanium

Global titanium demand is projected to reach a peak of 20 kt for low emission power generation by 2030, up from 5.5 kt in 2022.[294] This is driven primarily by its uses in nuclear energy. However, other applications of titanium in the automotive and aerospace & defence sectors means that true demand will likely be far greater.[295] From a supply perspective, the biggest concern is not the reserves or availability of ilmenite and rutile ores – which are used to produce titanium – but rather the dependence on current supply chains. The world's biggest supplier of titanium alloys to the aerospace and defence sector is VSMPO-Avisma, producing 45% of the world's aerospace titanium parts.[296] However, VSMPO-Avisma is in Russia, and as such there is widespread concern that this dependency could expose vulnerabilities in the event of any future sanctions or export restrictions.

289 T&F Group member interview October-November 2023.
290 Lucy Bloxham et al., "PGM market report," Johnson Matthey, May 2022.
291 IEA, "Critical Minerals Data Explorer," International Energy Agency, July 11, 2023.
292 Global Industry Analysis, "Comprehensive Analysis: Worldwide Tantalum Market," December, 2023.
293 IEA, "Critical Minerals Data Explorer," International Energy Agency, July 11, 2023.
294 ibid.
295 Limited publicly available data on the non-energy demand forecasts for titanium.
296 European Commission, "Titanium Metal: Impact assessment for supply security," European Union, 2022.

06

UK Projects & Infrastructure

UK Projects & Infrastructure

The Critical Minerals Intelligence Centre's (CMIC) interactive map, desktop research and T&F Group members expertise were used to identify planned and operational CRM infrastructure across the UK. This was further refined through qualitative output from industry stakeholder interviews and Department for Business and Trade oversight of project pipelines. CMIC's map showcases various new and existing datasets that are relevant to identifying critical mineral value chain development opportunities in the UK.[297] The datasets comprise geoscience data that supports the national assessment of UK geological potential for CRMs, along with the locations of specific mineral processors and refineries, chemical and metal production facilities, recyclers, and other development activities.[298] However, while some data shows promising geological potential, feasibility or environmental impact studies have not yet been conducted in these areas. Therefore, extraction may not be possible at some of these sites for 15-20 years, if ever.

This section takes a closer look at the UK's infrastructure projects, highlighting several that have the potential to improve the country's supply chain resilience in the next decade. It is worth noting that while improved UK production of CRMs can improve the UK's resilience, such supply is not guaranteed to be maintained in the UK economy as the CRMs produced could be traded via international markets to offtakers, either domestically or overseas. The information has been collated from CMIC's work, summarised in the appendix, along with additional desk-based research.

The UK has operations or projects at various stages of development that can extract, process and recycle a wide range of CRMS from tungsten mining to electronics recycling. To illustrate the UK's capabilities, this report considers three case studies for the following CRM's:

- **Lithium**
- **REEs**
- **Tin**

[297] UK Critical Minerals Intelligence Centre, "UK Critical Minerals Intelligence Centre," Accessed October-November, 2023.
[298] ibid.

Lithium

The risk methodology framework shows the key risks faced in the lithium supply chain are net import reliance, and high concentration of mining and processing. However, these risks can be reduced to some extent by investing in domestic infrastructure and increasing mining, refining, and recycling capabilities. The UK has the potential to achieve self-sufficiency in lithium production for EV battery manufacturing by 2030 if the right infrastructure and investment are in place, and if all current mining and brine extraction projects proceed as planned. This could position the UK as a net-exporter and a major player in midstream, recycling, and lithium production.[299]

There are ongoing projects that UK companies are engaging with that have the potential to provide significant supply of lithium to UK industry. The examples below are of projects that can provide supply should they come online, it is not meant to be exhaustive or provide an indication of which are more or less likely to succeed:

- Cornish Lithium has multiple projects in various phases of development, namely Trelavour, United Downs and Twelveheads. It is estimated these sites will be able to produce up to 10,000 tonnes of lithium per annum when fully operational from 2026 onwards. This would meet 20% of UK demand.[300] [301] Cornish Lithium has recently secured a £53.6 million funding package from TechMet, UKIB and EMG, followed by an additional crowdfunding campaign that raised £5.1 million from shareholders to begin operations.[302]
- Tees Valley Lithium Ltd (TVL) is the first independent lithium chemical processing hub in Europe, situated in Teesside, UK. TVL has secured a 20-acre plot on Sembcorp Energy's UK site at Wilton International and will operate under a 30-year lease agreement.[303] The company imports high-value feedstock from around the world and supplies battery-grade lithium to Europe. TVL's zero-waste lithium refinery will use state-of-the-art electrochemical processing to produce 96,000 tonnes per year of low-carbon battery-grade lithium at full production capacity.[304]
- Northern Lithium is a UK-based company that aims to produce battery-grade lithium from the Northern Pennine Orefield, which is in the northeast region of the UK. The company's initial project involves producing 5,000 to 10,000 tonnes per year of battery-grade lithium from up to 10 production sites in the region.[305] As of September 2022, the company confirmed that lithium was present in brines from its initial exploration borehole and has initiated drilling of a second borehole at Ludwell Farm.[306]
- Weardale Lithium is a UK-based natural resources exploration and development company located in County Durham's Weardale region, with a goal of providing a secure and sustainable domestic lithium supply. The company has successfully trialled multiple direct lithium extraction technologies to extract lithium from geothermal brines found in boreholes at Eastgate, County Durham. Weardale Lithium aims to produce approximately 10,000 tonnes of lithium per year.

While the extraction of lithium is an area of significant possibility within the UK, there are also growing initiatives and projects across the UK economy that are looking to take advantage of commercialising the end-of life recycling for lithium. Companies that are actively engage with such projects are British Lithium, Altilium Metals Ltd and Fenix Battery Recycling.

[299] T&F Group Interview, Thursday 2nd November 2023.
[300] UK Critical Minerals Intelligence Centre, "CMIC Web GIS Live (arcgis.com)," Accessed October-November, 2023.
[301] Cornish Lithium, "Cornish Lithium invites local community to find out more about its Trelavour Project," Accessed October-November, 2023.
[302] Cornish Lithium, "Another Quarter of Significant Progress for Cornish Lithium with Landmark Funding Secured," Accessed October-November, 2023.
[303] Tees Valley Lithium, "Leading the charge to Europe's Net Zero Future," Accessed October-November, 2023.
[304] Wilton International, "Tees Valley Lithium agrees long-term lease for lithium processing facility at Wilton International," December 15, 2022.
[305] Northern Lithium, "Unlocking critical domestic sources of lithium for the UK," Accessed October-November, 2023.
[306] ibid.

REEs

By 2050, the UK plans to have 75GW of installed wind capacity. This will require 93,000 tonnes of permanent magnets, equivalent to approximately 30,000 tonnes of REE.[307 308] Drawing upon the risk methodology and information provided by industry experts, key risks in REE supply chains include net import reliance and mining concentration. For example, China controls over 95% of global REE production and supply,[309] which leaves UK industry vulnerable to geopolitical risks, and supply chain shocks.[310] Increased domestic infrastructure for mining and processing REEs may ease these.

There are several companies working either in the UK, or which have operations overseas as part of a UK owned Group that are looking to enhance the extractive tonnage output of REEs that may impact supply to the UK:

- Ionic Technologies International (IonicTech – formerly known as Seren Technologies), is a wholly owned subsidiary of Ionic Rare Earths based in Belfast, UK. IonicTech specialises in the refining and recycling of REEs having developed a patented element separation process and refining technology.[311] The process has successfully produced recycled REEs in magnets that meet the specifications required by the automotive, aerospace and defence industries. IonicTech has built a plant to process ore samples and successfully demonstrated its technology producing high-purity rare earth oxides at 10 tonnes per year.[312]
- Less Common Metals (LCM) is a UK-based company that specialises in producing rare earth and other speciality metals for various industries including aerospace, automotive, electronics and renewable energy. Their products include neodymium iron boron and samarium cobalt magnets, as well as other rare earth metals like dysprosium, terbium, and yttrium.[313] Since 2017, LCM has been commercially producing neodymium and neodymium praseodymium metal on their premises in the UK, with a production capacity of over 120 tonnes per year.[314]
- Ozango Minerals, a subsidiary of Pensana Plc, received approval to extract REEs from the Longonjo Rare Earths project in Angola. The extracted REEs will be transported to the UK for refining. Pensana Plc intends to export up to 40,000 tonnes of mixed rare earths sulphate from the mine to be processed at its refining site in Saltend, UK.[315] Pensana is estimated to refine 12,500 tonnes of REEs per year when fully operational but is currently at an early stage.[316]

Beyond examples of increasing primary supply companies are also looking at the circularity of REEs. For UK REEs, IonicTech, LCM, and Ford are collaborating to create a demonstrative circular supply chain that is looking to leverage innovative technologies to establish high-specification magnets containing 100% recycled REEs for use in EVs.[317]

[307] Patricia Alves Dias et al., "The Role of Rare Earth Elements in Wind Energy and Electric Mobility," European Joint Research Council, 2020.
[308] Task & Finish Group Member Interview, October-November, 2023.
[309] Divya Rajagopal, "Western miners target China's rare earth metals grip with premium prices," Reuters, November 8, 2023.
[310] T&F Group Interview, October-November, 2023.
[311] Ionic Rare Earths, "Ionic Technologies Belfast Facility Update," December 12, 2022.
[312] Ionic Technologies, "Rare Earths for Life," Accessed October-November, 2023.
[313] Less Common Metals, "Less Common Metals," Accessed October-November, 2023.
[314] London Stock Exchange, "Supply Agreement with UK-Based Less Common Metals," September 11, 2023.
[315] Pensana Plc, "2023 Annual Report," October 30, 2023.
[316] UK Critical Minerals Intelligence Centre, "CMIC Web GIS Live (arcgis.com)," Accessed October-November, 2023.
[317] Less Common Metals, "LCM Partners with Ionic Technologies and Ford for Re Magnet Recycling in the UK," September 14, 2023.

Tin

Tin belongs to a set of materials that includes tin, tungsten, tantalum, and gold (3TGs). These materials are commonly referred to as conflict minerals due to the location of their mining. Such assessment provides them with a heightened supply chain risk due to the potential risks such as use of child labour or environmental exploitation in the extraction.

The UK has an opportunity to increase domestic supply of tin through the Cornish Metals' South Crofty project. The project holds the fourth largest tin mineral resource globally and shows that the UK can position itself globally on some CRMs. The project has received approval for mining and operation with construction expected to begin shortly. The mine is projected to reopen by 2026.[318] A significant benefit of the South Crofty project is that it could help mitigate the risks related to the extraction of 3TGs given the nature of operations in the UK. It has the potential for the UK to show leadership on the performance of operations for tin. An additional benefit of the project is reducing the net import reliance for UK industry, as around 75% of the global tin production comes from China, Myanmar, and Indonesia, leaving the UK vulnerable to supply shocks.[319] A key challenge related to tin that will need to be considered is that there is currently no smelting of tin in the UK or Europe.

Overall, increased investment in UK infrastructure is expected to have a considerable impact on domestic mineral supply chains in the future. By continuing to reduce import reliance and promoting onshore supply chains for key CRMs, the UK can improve its sovereign capabilities to become less vulnerable to supply chain disruptions.

It is worth noting the projects identified in this section may affect future supply, but it will take time for them to reach full operational capacity. This will bring long-term benefits to the UK economy including greater ability to engage when negotiating international trade deals and partnerships, which can help secure a broader suits of CRMs than the UK produces domestically. It does not resolve however, short-term demand from domestic supply resulting in the need for imports.

[318] Cornish Metals, "Cornish Metals Files Technical Report for the South Crofty Tin Project Mineral Update on SEDAR," October 30, 2023.
[319] ibid.

07

International Collaboration

Picture Source: https://www.tradeandbusiness.uk/free-trade-agreements

International Collaboration

The global trade of CRMs is evolving. Multiple countries and regions are entering into free trade agreements, partnerships, signing memorandums of understanding (MOUs) or statements of intent (SOIs), and making investments to help secure access to CRMs. Such measures can be important for strengthening continuity of supply and improving resilience.

This section provides a summary of the UK's agreements and partnerships alongside those of their trade partners. The list is non-exhaustive and serves to provide insight into the strategies employed by different countries to build CRM resilience and to promote sustainable mining practices. As the dates in the table indicate, the past two years have seen a proliferation of mechanisms for international collaboration and bilateral partnerships on a national level.

Beyond such partnerships and trade agreements, there is a growing space for international public/private partnerships to drive greater collaboration of actors across value chains to bridge the gap of supply and demand. There are several significant initiatives already, such as the Industrial Deep Decarbonisation Initiative,[320] World Economic Forum's Fist Movers Coalition,[321] Circular Electronics Partnership[323] and Global Battery Alliance.[324] We are also seeing forums being established to provide an area for discussion on such partnerships such as the Critical Minerals International Alliance.[325] It is important that as partnerships are built on production of materials, emphasis be placed on cooperation with producing nations, such as the Resilient and Inclusive Supply-chain Enhancement (RISE) initiative.[325]

A challenge highlighted by T&F Group members is that while the political and regional trade positions are evolving it has been challenging for companies in the UK to clearly point towards how these have impacted the flow of minerals into the UK. These new partnerships often do not provide UK companies with preferential access. It is therefore important for UK Government to look at what role they can have in future negotiations that might provide greater access for companies in the UK through the various types of engagement they can have with relevant countries, regions, or other stakeholders.

Partnerships

The UK has signed numerous partnership agreements with other countries to enhance the investment and trade of CRMs. There are also several global partnership initiatives underway such as the IEA working group or G7 work on critical minerals.

Heading	Countries	Type	Description
Minerals Security Partnership[326]	Australia, Canada, EU, Finland, France, Germany, Japan, South Korea, Sweden, US, and UK	Multilateral Partnership	Launched in June 2022, the MSP is a collaboration of 13 countries and the EU with the aim of catalysing public and private investment in responsible critical minerals supply chains globally. The partnership focuses on diversifying and stabilising global supply chains, enhancing investment, promoting high ESG standards across critical material supply chains, and increasing recycling of critical minerals.[327]

[320] UNIDO, "Industrial Deep Decarbonisation, an Initiative of the Clean Energy Ministerial," Accessed October-November, 2023.
[321] First Movers Coalition, "First Movers Coalition," Accessed October-November, 2023.
[322] Circular Electronics Partnership, "The biggest names in tech, consumer goods and waste management working together for a circular economy," Accessed October-November, 2023.
[323] Global Battery Alliance, "Establishing a Sustainable and Responsible Battery Value Chain," Accessed October-November, 2023.
[324] Critical Minerals International Alliance, "Building Resilient, Diversified & Responsible Critical Minerals Supply Chains," Accessed October-November, 2023.
[325] The World Bank, "World Bank and Japan to Boost Mineral Investments and Jobs in Clean Energy," October 11, 2023.
[326] Department for Business & Trade & Nusrat Ghani PM, "UK to host Minerals Security Partnership for first time to boost investment in critical minerals," October 11,2023.
[327] U.S. Department of State, "Minerals Security Partnership," Accessed October-November, 2023.

Heading	Countries	Type	Description
UK-South Africa partnership on minerals for future clean energy technologies[328]	UK & South Africa	Bilateral Partnership	Launched in November 2022, aims to encourage responsible exploration, development, production, and processing of minerals in South Africa. The country is a major producer of minerals such as platinum, palladium, iridium, vanadium, and manganese. Additionally focuses on supporting increased investment flows into the minerals mining sector and growing clean new jobs.
UK-Saudi Arabia Declaration of Intent[329]	UK & Saudi Arabia	Bilateral DOI	Launched in January 2023, followed by the signing of a Declaration of Intent in May 2023, aims to diversify sources of CRMs by encouraging Saudi investment in the UK's manufacturing and mining finance sectors and seeks to create new opportunities for UK mining firms to conduct business in Saudi Arabia. The partnership also builds on transparency and environmental standards to minimise the risk to business and encourage investment.
UK-Canada Statement of Intent to boost green tech supply chains and Critical Minerals Supply Chains Dialogue[330]	UK & Canada	Bilateral SOI	Launched in March 2023, this SOI sets up a stronger collaboration with Canada to bolster the vital technologies such as smart phones, solar panels and electric vehicles. It promotes collaborative CRM research and expresses commitment to make supply chains more resilient to meet the growing demand.
UK-Australia Critical Minerals Statement of Intent[331]	UK & Australia	Bilateral SOI	Signed in April 2023, this aims to promote investment opportunities in clean energy technologies and upstream extraction, while supporting net zero commitments and to promoting high ESG standards in CRM processing.
UK-Kazakhstan Memorandum of Understanding on critical minerals[332]	UK & Kazakhstan	Bilateral MOU	Signed in March 2023, aims to promote investment and cooperation, with Kazakhstan having globally significant reserves of CRMs that are strategically important for the UK.
UK-Zambia Memorandum of Understanding on critical minerals[333]	UK & Zambia	Bilateral MOU	Signed in August 2023, aims to support Zambia's efforts to maximise benefits from its resources and attract foreign direct investment, and aims to promote responsible mining of minerals that are crucial for the energy transition. This also lays the foundation for further UK support for the responsible mining of copper, cobalt, and other metals for the energy transition.
UK-Japan Memorandum of Cooperation on Critical Minerals[334]	UK & Japan	Bilateral MOC	Signed in October 2023, the Memorandum of Cooperation provides a framework for deepening critical minerals cooperation and promoting dialogue on a range of areas including research and innovation as well as infrastructure projects in third countries.
UK-US Critical Minerals Agreement (negotiation)	UK & US	Bilateral Scoping partnership	As part of the Atlantic Declaration announced by the Prime Minister and President Biden in June 2023, the UK launched negotiations on a Critical Minerals Agreement, supporting a strategically important sector of the UK economy and bolstering vital supply chains.

Figure 22: UK partnership agreements

[328] Department for Business, Energy & Industrial Strategy and Department for Energy Security & Net Zero, "UK and South Africa working in partnership on minerals for future clean energy technologies," UK Government, November 23, 2022.
[329] Department for Business, Energy & Industrial Strategy and The TH Hon Grant Shapps MP, "UK and Saudi Arabia pledge to deliver closer co-operation on critical minerals," UK Government, January 11, 2023.
[330] Department for International Trade, Department for Business & Trade and Nusrat Ghani MP, "UK and Canada sign agreement to boost green tech supply chains," UK Government, March 6, 2023.
[331] Department of Industry, Science and Resources, "Australia and UK sign statement of intent to support critical minerals sector," Australian Government, April 4, 2023.
[332] Ministry of Foreign Affairs of the Republic of Kazakhstan, "Strengthening of Comprehensive Partnership Discussed with UK Secretary of State at Kazakh Foreign Ministry," Kazakhstan Government, March 18, 2023.
[333] Foreign Commonwealth & Development Office & Rt Hon James Cleverly MP, "UK supports green growth in Zambia," UK Government, August 3, 2023.
[334] Department for Business & Trade et al., "UK-Japan Critical Minerals Memorandum of Cooperation," UK Government, October 28, 2023.

Trade agreements

Trade agreements are more impactful that partnerships when it comes to driving changes in access to additional supply of CRMs. These are harder to agree given they often come as part of wider trade deals, but given the scale of demand for CRMs they are now increasingly being engaged on in bilateral agreements as a standalone topic.

Such trade agreements come with compliance obligations with value-add rules for processing. For example, this is important to qualify downstream use in the US Inflation Reduction Action subside-qualifying industrial sectors.

Heading	Countries	Type	Description
US-Japan FTA	US & Japan	FTA	The US and Japan have signed a CRMs Free Trade Agreement.
US-EU FTA	US & EU	FTA	The US and EU are in the final stages of concluding a CRMs Free Trade Agreement.
N/A	US & Indonesia	Scoping partnership	The US and Indonesia have initiated negotiations for a free trade agreement that includes CRMs. Indonesia has proposed a limited FTA to the US.
EU & Argentina Memorandum of Understanding	EU & Argentina	MOU	The President of the EU Commission and the President of Argentina have signed a Memorandum of Understanding to establish a partnership between the EU and Argentina on CRMs value chains.
EU & Chile Statement of Intent	EU & Chile	SOI	The EU and Chile have progressed towards ratification, as the Commission has sent the Advanced Framework Agreement (AFA) and the Interim Trade Agreement (ITA) to the Council for authorisation of signature.
N/A	EU & DRC	Scoping partnership	The EU is currently in negotiations with the Democratic Republic of Congo regarding the supply of CRMs.
Australia-India Economic Cooperation and Trade Agreement	Australia-India	Partnership	Australia and India have an ongoing strategic and economic partnership, and the Australia-India Economic Cooperation and Trade Agreement (ECTA) will promote growth and investment in Australian CRMs. The agreement included the elimination of tariffs on December 29, 2022.
N/A	Japan, Namibia, the DRC, Zambia	Investment	Japan has signed CRMs investment agreements with Namibia, the DRC, and Zambia.
Canada & Chile Statement of Intent	Canada & Chile	SOI	Canada and Chile have released a joint statement of intent to establish a CRMs trade partnership.
N/A	Germany, Argentina, Chile	Scoping partnership	Germany is currently engaged in discussions with Argentina and Chile to enhance their CRMs trade partnership.

Figure 23: International trade agreements

08 Recommendations

Recommendations

This report demonstrates how a lack of CRM resilience is an increasing risk to UK industry. The rising demand for CRMs across the globe, largely driven by the net-zero transition, further exposes the UK's economy to international competition. The UK's position is not akin to some other similarly developed countries and geographies, such as the US, Australia, and the EU which all have significant domestic mineral reserves, and/or are already taking more aggressive and targeted approaches to secure supply to CRMs. To remain competitive and meet the growing demands of UK industry, the UK should consider focusing attention on building capability in midstream processing, as well as building a circular economy to capture the value of materials already in the country. These are both high value-add areas where the UK could have a competitive edge though its access to technology and finance.

The UK Government has already made some progress in securing CRM supply for the UK, to meet its current and future needs. Interventions to date include allocating funds specifically to this policy area; assembling the independent T&F Group to enhance public-private partnerships and develop a shared approach; and collaborating with international partners, including recent partnerships agreed through the Minerals Security Partnership, International Energy Agency and G7, alongside several MOUs (as described in this report). However, this is simply the beginning and the UK needs to act now to build resilient CRM supply chains to robustly secure supply for key UK industries.

The following recommendations from the T&F Group aim to provide concrete follow up actions for both the UK Government and Industry, to increase CRM resilience both now and through to 2050.

1

Develop a long-term vision on industry resilience that includes CRMs for the UK

The UK needs to establish a long-term vision on industry resilience, including CRMs, with ambitious goals that foster a culture for investment in innovation, adaptability, and shared responsibility. The UK should set priority industries and materials based on national priorities and competitive advantage. For example, industries such as defence, aerospace and automotive are major drivers of economic growth and employment, while at the same time the necessity of the transition to net-zero underlines the strategic importance of the energy sector. Based on these sector priorities the UK can prioritise which CRMs are needed to support these manufacturing sectors, using the outcome of this report and the work of CMIC, including the upcoming Criticality Assessment (to be released in mid-2024). When priorities have been set, industry can focus resources to fill the infrastructure, skills and financing gaps in these supply chains building resilience into key industries, with the necessary security of intended direction and support from Government.

Government and industry stakeholders will need to collaborate closely to account for diverse perspectives and competing priorities. The demand trends may change significantly in the future, depending on the sectors' business models, market trends, innovation, and the impacts of the net-zero transition, as indicated in this report. Therefore, a forward-looking approach will be needed to develop an evidence-based vision. This will require richer and better data than the T&F Group was able to access in preparing this work, which in turn will require consistent investment (via CMIC and others) to develop and maintain.

[229] UK Critical Minerals Intelligence Centre, "UK Critical Minerals Intelligence Centre," Accessed October-November, 2023.

[230] ibid.

[231] T&F Group Interview, Thursday 2nd November 2023.

[232] UK Critical Minerals Intelligence Centre, "CMIC Web GIS Live (arcgis.com)," Accessed October-November, 2023.

[233] Cornish Lithium, "Cornish Lithium invites local community to find out more about its Trelavour Project," Accessed- October- November 2023.

[234] Cornish Lithium, "Another Quarter of Significant Progress for Cornish Lithium with Landmark Funding Secured," Accessed October-November, 2023

What will this mean for the future of UK critical raw mineral resilience?

A long-term vision will align the link between CRMs, Government's broader net zero agenda and the wider economy.

A policy setting out the long-term vision on industry resilience that includes CRMs, released in 2025, with clear milestones till 2040, will enable collaboration between Industry and Government to ensure sectors that are vital to the UK's security can thrive, building resilience by securing the necessary materials for key applications. Crucially, a living, evidence- based strategy co-developed with industry will enable the country to respond to emerging trends to avoid being caught off guard in an area fraught with geopolitical, environmental and social risks.

2 Enhance CRM supply chain transparency though improved data availability to support decision making

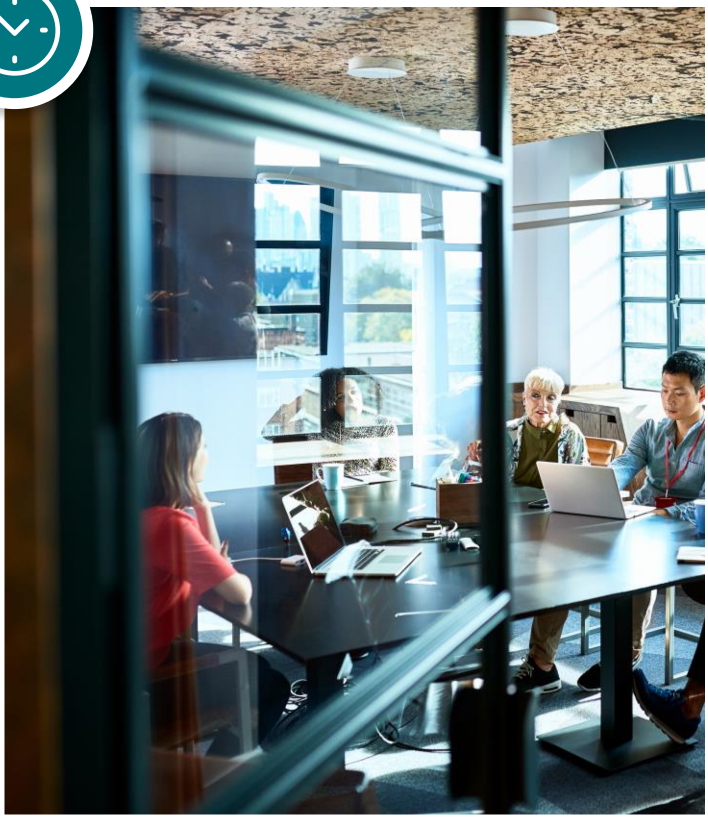
Enhancing material and supply chain transparency is one element to building a better picture of supply risks and ESG supply chain impacts. Enhancing data quality is a useful tool for decision making which requires collaboration across the supply chain and utilising the necessary technological tools. Manufacturers should look to augment their tier 1, 2, 3 supplier relationships with data requirements and focus on building capacity across the supply chain to maximise the collection of data across both supply and ESG indicators.

A collaborative approach should be taken when developing a standardised process for monitoring and mapping CRM supply risks across UK industrial sectors using interoperable and innovative technologies. For example, the EU is using digital product passports as a tool to enhance supply chain transparency through a uniform approach across different product categories, starting with batteries. Government and Industry should apply the insights gained from previous experiences of supply chains resilience being tested, such as during the Covid-19 pandemic when multiple supply chains faced numerous challenges.

To ensure a transparent account of CRMs, Government, with support of industry and research communities, should seek to accelerate work on critical minerals data, with an initial focus on tracing the flows of CRMs into and through the economy. This should take account of both the National Materials Datahub concept and of the wider global supply chains environment including a stocktake of the critical resources that are currently contained in UK infrastructure and, as far as possible, products and their end-of-first-life treatment.

What will this mean for the future of UK critical raw mineral resilience?

Better data will enable manufacturers to understand more about their supply chains and material provenance. This will improve understanding of their supply chain vulnerabilities, bringing this key issue to boardrooms, no matter how far down the sourced commodities are in the supply chain. A focus on improving CRM supply chain transparency will give individual businesses incentive to improve data gathering and sharing through their entire value chain, based on an enhanced direct dialogue with suppliers. The Government, meanwhile, will benefit from knowledge of where materials flow in the economy and forecasts of the CRM needs of different sectors, which will create an aggregated picture of material demand to encourage evidence-based approaches. Improved traceability and access to data will enable planning for investments and infrastructure and boost UK competitiveness and resilience. For example, understanding stocks of materials in current assets will enable planning for infrastructure for recycling and reuse.



3

Build on the UK's competitive advantages and develop its midstream economy

The UK possesses numerous strengths that can be leveraged into positioning the UK as a 'Centre for CRMs'. These include expertise in innovation, attractiveness to business, openness to trade, leading academic institutions and a world leading financial sector, which leads to many companies in critical sectors being headquartered in the UK. These strengths can be harnessed to support the goal of building a globally competitive midstream industry by securing investment in long-term enabling infrastructure projects and creating a thriving innovation eco-system. By having a robust midstream infrastructure, the UK can enhance the resilience of its critical raw minerals supply chain as the processing and refining capabilities it encompasses reduces dependency on raw material imports and helps mitigates supply chain vulnerabilities.

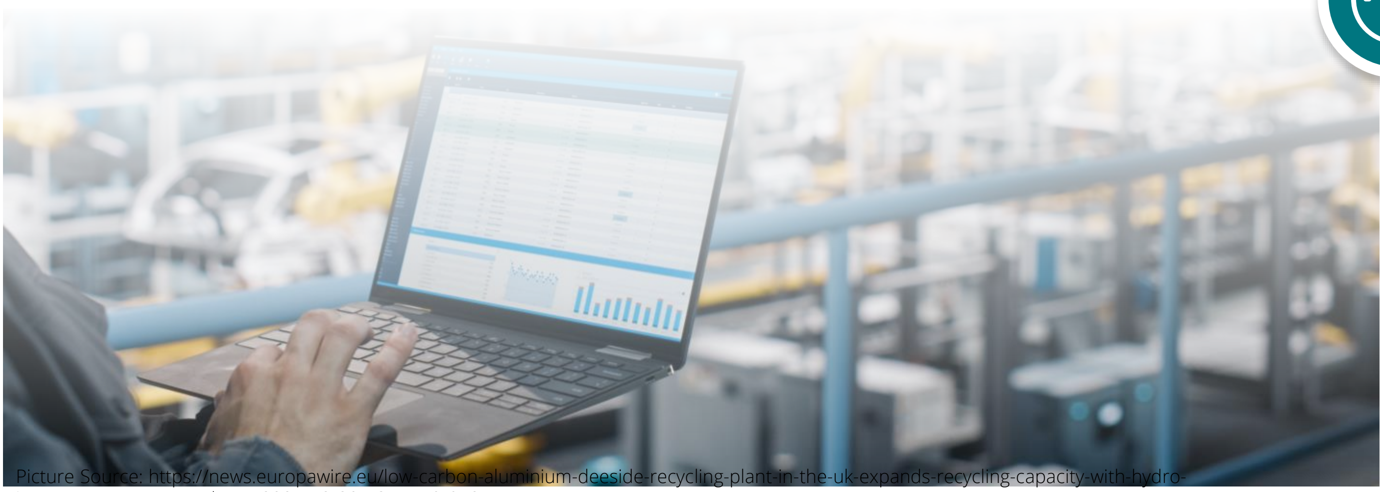
The carbon savings achieved through efficient recycling significantly surpass those from traditional mining, potentially reaching as high as 98%. Recognising the value of quantifying these carbon savings could serve as an incentive to promote effective recycling. For instance, implementing a program like R&D tax credits but focused on carbon could be explored. The Government could help to drive this forward through tracking progress against key performance indicators but also by showing leadership and convening key cross-sector leaders in these industries around a concrete set of priorities and actions.

Continued investment through capital grants and financing into research and development is crucial for enhancing supply chain resilience and exploring technological alternatives that decrease reliance on critical minerals, government should continue to provide financial incentives to support this. Government should also focus on removing disincentives by, for example, lowering energy costs for industries and simplifying and prioritising and allocating sufficient resourcing to accelerate the permitting of midstream and end of life processing projects.

Another important focus should be on capturing materials imported into, mined, and processed in the country, creating a robust industry for reprocessing and reuse. It is essential to set direction to scale up efforts at pace and find effective methods to retain and process materials domestically. Further measures could be explored, for example consideration should be given to the EU's approach to setting targets for domestically sourced CRMs and the inclusion of recycled content. The ongoing monitoring of CRM risks to supply chains could be tracked live by the Government using a technological platform.

What will this mean for the future of UK critical raw mineral resilience?

With midstream processing, like material refining and component manufacturing, neglected globally, the UK can carve out a niche. This could form part of a UK response to the US's Inflation Reduction Act and related efforts from the European Union that will see considerable investment in domestic clean energy infrastructure. Investing in and developing midstream activities will be uniquely suited to the UK's strengths, as a hub of innovation and competitive businesses, while addressing the weakness of having relatively few accessible reserves of critical materials needed for the country to thrive. By moving quickly, the UK could become a key player in supply chains providing the materials and components needed to enable a successful global transition to net zero.



Picture Source: https://news.europawire.eu/low-carbon-aluminium-deeside-recycling-plant-in-the-uk-expands-recycling-capacity-with-hydro-investment/eu-press-release/2021/12/20/13/47/59/94844/

4 Take a shared approach between Government and Industry to build a robust circular economy for CRMs

The current circular economy capabilities within the UK are not sufficient to maximise the resource efficiency of CRMs. Circular economy supply chains encourage the efficient design and use of resources to minimise waste and maximise the utilisation of materials through reducing demand, repairing, remanufacturing, and recycling. Demand reduction strategies, such as minimising the use of cobalt, adopting thrifting practices for platinum, and efforts to decrease the reliance on iridium in electrolysers, exemplify the initial principle of the circular economy. This approach is something that industry can actively engage in, in contrast to broader demand reduction strategies like modal shifts in transportation, which may not be directly within the industry's control.

The UK Government can leverage their market influence, through for example, financial grants, to provide a strategic advantage to businesses investing in and offering circular economy solutions (e.g., setting standards for EOL treatment, or life extension, for wind turbines in their long-term contracts). This can assist businesses in investing in cutting-edge infrastructure and technology essential for enhancing the circularity of their operations. Constructing these innovative circular models demands the development of new capabilities and collaborative efforts, often necessitating cross-industry cooperation. This applies to both large and small enterprises, where often government incentives are required to drive such collaboration and increase the engagement in these endeavours.

The stringent waste classifications imposed by the Environment Agency (EA) inadvertently creates barriers to the international movement of waste containing CRMs, such as electronic waste, industrial by-products, or discarded products. This restriction limits the smooth flow of materials that could otherwise be recovered, recycled, and utilised in various industrial processes. The limitations imposed by EA's waste classification hinder the potential for cross-border collaboration in the recovery and recycling sector.

Therefore, there is a pressing need for regulatory adjustments that strike a balance between environmental protection and the promotion of sustainable resource management, allowing for the unhindered transboundary movement of specific CRMs within waste and by-products. Additionally, the Government can support by simplifying the 'End of Waste' application process so that a waste carriers license is not required for the transport of some metals and minerals.

Government can also help by simplifying UK Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) guidance, focusing on CRMs. REACH was originally intended to apply to harmful chemicals and substances but is also required for non-hazardous metals. Simplification and enhancement of this regulatory framework would prove beneficial in mitigating these issues and fostering more effective compliance across industries.

Governments can promote an inclusive approach to industrial symbiosis by encouraging collaboration across different sectors. Industrial symbiosis involves engaging with industries that may not traditionally consider symbiotic relationships to determine opportunities for advantageous exchange of waste, materials, energy, water, and by-products amongst them to increase resource efficiency. The development of shared industrial parks to stimulate a place-based industrial symbiosis should not be overlooked, particularly given its success in industrial centres.

What will this mean for the future of UK critical raw mineral resilience?

A successful approach to a circular economy, including developing and executing a pipeline for recycling and reuse infrastructure and an enabling environment for industrial symbiosis, will minimise the UK's exposure to volatile international markets. This will significantly reduce reliance on imports of raw materials and allow the country to make best use of the considerable stocks of materials that will be continually building up in the country's products and infrastructure, as existing and planned energy infrastructure mean that the UK is becoming an ever more resource rich country. A shared approach will encourage a thriving research and innovation sector and will give industry incentives to increase recycled content in the near future and to go on increasing it, as well as improving design decisions, decommissioning and end of life handling and reuse of CMMs.

5 Implement strategic international partnerships, trade deals, friend shoring

CRMs are used to some degree across nearly all manufacturing industries and sectors globally. The Government can play a large role as a convenor to facilitate partnerships, alliances, and identify opportunities to improve the resource efficiency of CRMs when bringing together sectoral players across geographies. Together, they can increase resource optimisation, secure access, accelerate innovation, and contribute to a more resilient industrial landscape.

The UK's CRM security depends on having direct physical access to critical minerals, whether sourced domestically or internationally. Relying solely on critical mineral agreements does not ensure security, as there is no guarantee that, in the event of export bans in certain countries that our partner nations will sufficiently supply critical minerals to support the UK's industrial needs.

While the UK Government is actively addressing trade barriers with specific countries, there remains room for further improvement. Prioritising the mitigation of geopolitical risks with key producer countries should be central. A collaborative effort between Government and industry is essential to realise opportunities, potentially requiring additional funding for projects aimed at expanding or introducing new infrastructure to close supply chain loops. Coordination with industry is also important when it comes to identifying the scope of potential trade agreement and partnerships to support the critical aspects for each priority sector relative to the peer country.

When establishing strategic partnerships, careful consideration is necessary to avoid constraints on deal scope. This involves accounting for factors such as competition law, commercial sensitivities, and waste classification standards. In addition, Government should increase focus on leveraging already existing trade deals and MOUs and ensuring that these are appropriately translated to action. Signing an MOU should be seen as the start of the strategic collaboration between Governments, not the end. Resources should be made available for Industry to engage with the different trade deals that Government may have signed, and strategic decisions should be made to ensure that the deals that are being prioritised are those which will bring maximum returns to UK industry.

Further work can be done to support UK companies in the global mining sector to promote new, diverse, responsible sources of supply from overseas. Addition support can be provided for developing countries by resource mapping supply chains and exporting UK mining equipment to help close supply chain loops.

What will this mean for the future of UK critical raw mineral resilience?

Diversifying the CRM production base away from currently dominant countries like China and enhancing trade agreements and relationships with partners and allies will limit the UK's exposure to geopolitically fraught supply chains. This will be crucial as the entire world is attempting to decarbonise by 2050, which the IEA has suggested will require a six fold increase in mineral inputs to clean energy technologies. At the same time, many of those same minerals will continue to be needed by industries including aerospace and defence, electronics, and medicine at home and abroad, so a diverse supply base, complemented by measures to reduce demand for these materials, will be the best way to ensure needs can be met.

6 Adopt a holistic approach to assess the environmental and social impacts of CRM supply chains

A holistic approach is needed to determine the broader environmental and social impacts associated with CRM supply chains and the interventions suggested to improve resilience. To effectively address broader environmental and social risks, robust due diligence processes should be implemented and continually improved.

When exploring alternative materials or substitutions, it is essential to be cautious and avoid compromising health and safety standards, alongside overall product standards (e.g., a replacement of a specific material that significantly decreases the lifespan of the product, should be carefully weighed against alternatives).

What will this mean for the future of UK critical raw mineral resilience?

Due diligence requirements to responsibly source CRMs will be vital to ensuring that activity in the UK does not irreparably damage communities and ecosystems abroad where materials are mined or processed. Traceable supply chains and minimised impacts will enable the UK to be a world leader that can export systems and knowledge. This will require coordination from Government and an eye on ensuring requirements are not counter-productive to supply. They can build on recent efforts in both the UK and the EU and will involve ever improving traceability of supply chains to prevent deforestation and biodiversity loss, to mitigate pollution and to ensure that human rights are protected. This will include by eliminating child labour and worker exploitation while respecting the rights of indigenous communities wherever materials are mined.

7 Support UK skills and innovation development

There is an overarching need to increase the level of skills to stimulate innovation in the UK, focusing on enhancing CRM supply chain resilience. Support should be provided for skills development and scaling up impactful SMEs that increase the UK's supply chain resilience. It is important that Government endorses fields related to midstream CRM supply chains and circular economy as promising areas for the future to encourage life-long learning. This support aims to encourage skilled individuals to enter the sector and increase technical proficiency and innovation. Fostering a collaborative approach will help model and test the CRM cross-sectoral supply chain resilience, to avoid the assessments are not conducted in industrial silos.

Additionally, the UK Government should seek to support the further development of the circular economy, exploring opportunities for research and development through collaboration with industry and fostering cross-collaboration across different players. Collaborating with and convening the UK's rich base of academic researchers, SMEs, and companies involved in repair, refurbishment, and re-manufacturing is critical as is raising public awareness on the benefits of the circular economy, particularly initiatives like deposit return schemes is key to enabling this. The UK can also offer this support to other developing and partnering companies as ultimately improving the resilience of CRM supplies globally will benefit the UK's own resilience as a result.

What will this mean for the future of UK critical raw mineral resilience?

The UK has a thriving, highly skilled workforce equipped to develop the midstream processing and circular economy supply chain opportunities that will deliver long-term resilience for UK industry.

09

Appendix

1 Appendix 1: Exhaustive list of CRMs in scope of this report

Aluminium	Gallium	Molybdenum	Silicon
Antimony	Germanium	Nickel	Strontium
Beryllium	Graphite	Niobium	Tantalum
Bismuth	Hafnium	Palladium	Tellurium
Boron	Indium	Platinum	Tin
Chromium	Iridium	Phosphates	Titanium
Cobalt	Lithium	REEs	Tungsten
Copper	Manganese	Rhenium	Vanadium
Fluorite	Magnesium	Rhodium	Zinc
	Zirconium		

2 Appendix 2: Risk framework methodology and limitations (1)

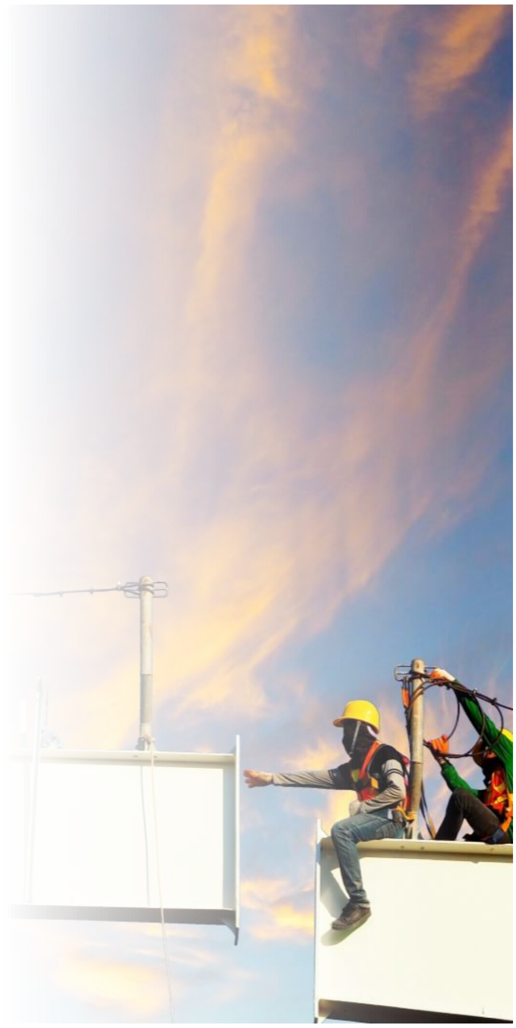
Selection of CRMs in-scope

This risk assessment was designed to test risks across a broad set of CRMs with strategic importance to UK industry. To do this, minerals and metals were selected from two sources: the materials in-scope for the 2021 BGS criticality assessment, and the minerals and metals mentioned by Task & Finish Group members during the workshops held during the year. This approach means that the range of materials included in the assessment should be those with the most strategic importance to UK industry.

Set risk categories for assessing minerals and metals

To effectively assess CRM supply chain risks, the risk assessment framework is divided into three categories: sector risk exposure, supply risk, and environmental & social risks. These categories each represent different areas of supply chain risk and are based on existing literature on criticality notably Graedel's methodology for the criticality of metals and metalloids and the work of the BGS. Together, they inform a comprehensive assessment of supply chain risk:

- Sector risk exposure looks at the material dependency of each industry-sector in scope, i.e., the impact of a material on a sector's ability to operate;
- Supply risk looks at the security and reliability of supply chains for each mineral, i.e., the likelihood of disruption to supply chain; and
- Environmental and social risks look at the impact that CRM supplies have on planet and society, i.e., understanding how industry mineral requirements can have adverse effects both upstream and downstream.



Indicator selection

The indicators selected within each category of this risk assessment cover a wide range of factors, each with the potential to cause supply chain disruption for UK industry if not managed appropriately. The selection process for these indicators was three-fold:

- Review those used in Graedel's criticality of metals and metalloids methodology and through a wider literature review select the ones of most value to the risk assessment;
- Consider industry best-practice for assessing supply chain risk;
- Receive input from Task & Finish Group members and Government on other indicators which could be of value to the risk assessment and in some cases create customized indicators pertaining to UK industry

A full list of the indicators used in the risk framework can be found below in Appendix 3. These are the indicators that were selected based on the three steps above and had a public data source available, that was deemed viable for the first version of a risk assessment framework.

Database selection

Once a provisional set of indicators had been selected and agreed on, a research exercise was conducted to identify databases that could be used. These databases are all from publicly available sources to allow the risk monitoring framework to be used again in the future without any additional cost. However, Appendix 3 provides an alternative set of private data sources which could be used to input into the framework when it is re-used later and could lead to better data coverage and quality.

During the research exercise, there were several indicators where public data was not available or was insufficient for input into the framework. As such, these indicators were not included in this risk assessment. However, Appendix 3 shows a list of these indicators which could be included in the future provided better data becomes available or can be purchased from private sources.

2 Appendix 2: Risk framework methodology and limitations (2)

Input data

Once the set of indicators and their respective data sources had been finalised, the data was inputted into the risk framework, which is hosted in excel. The data for each indicator was extracted based on mineral and country of origin – where applicable – to provide an accurate representation of risk profile across all indicators. For the sector risk exposure indicator, this report used primary data surveying members of the T&F group, key industry associations and other industry stakeholders, holding a series of interviews and in a workshop, this method was used to gain a more complete picture of the material dependencies of UK industry.

Data normalisation and scoring

To determine the relative risk rating for minerals and metals in the framework, it is key that datapoints for each indicator are normalised using a common scoring methodology. For consistency across all indicators, a 1-5 score has been assigned to all minerals in the framework. This has been achieved using standard deviation – where full datasets exist for the indicator – and alternative scoring criteria where the full data set is unavailable. A full breakdown is included in Appendix 3.

To determine risk scores for each category, the following approach was taken:

- For sector risk exposure, a 1-5 material importance score was assigned to each mineral/metal used by the industry, as identified in workshops, survey responses and interviews. This is the 'impact' score of mineral dependency in specific sectors.
- For supply risk, an overall score is calculated using an average of the indicator scores. This score is the same regardless of industry and represents the likelihood of supply chain disruption for each mineral.
- Similar to the supply risk score, the environment and social score is calculated using an average of all indicators in the category, and this remains the same regardless of sector.
- For the compound sector supply risk score, the sector risk exposure score and the supply risk average score are multiplied. This emulates the 'impact X likelihood' approach often used to quantify risk.
- To visualise risk scores for each sector based on mineral dependency, the top 10 most important minerals for each sector have been plotted in RAG charts, with the sliding scales showing risk per sector.

3 Appendix 3: Cross-cutting sector database template

Category	Indicator	Rationale	Scoring	Source	Limitations	Future improvements
Sector risk exposure	Material importance	Material importance demonstrates sector dependency on a CRM and indicates potential impact of supply chain disruption on manufacturers	Scored 1-5 per CRM	Workshops, survey, interviews	Indicator is solely based off information obtained from industry and trade associations making the sample size per industry small which could lead to gaps.	Gather material importance data from a larger pool of industry representati-tives.
Supply risk	UK trade Concentration	UK trade concentration shows tconcentrationhe diversity of the UK's trading partners for different CRMs	% concentration as defined by the Herfindahl-Hirschman index using the top three countries.	P A J Lusty, et al. (2021), 'UK criticality assessment of technology critical minerals and metals', British Geological Survey.	Data unavailable for the following CRMs: aluminium, antimony, beryllium, bismuth, boron, chromium, copper, fluorite, hafnium, iridium, platinum, phosphates, rhenium, rhodium, strontium, zinc, zirconium.	Identify whether a broader dataset is available which covers all CRMs being reviewed. Or use primary data to improve the database.
	Net import reliance	Net import reliance shows the extent to which the UK's CRM supplies depend on imports.	% reliance on imports	P A J Lusty, et al. (2021), 'UK criticality assessment of technology critical minerals and metals', British Geological Survey.	Data unavailable for the following CRMs: aluminium, boron, chromium, copper, fluorite, hafnium, iridium, phosphates, rhodium, zinc, zirconium.	Identify whether a broader private dataset is available which covers all CRMs being reviewed.
	Recycling rates	Recycling rates show the proportion of CRMs that are recovered for secondary use.	Scored 1-5 per CRM	1. T.E Graedel et al. (2011), 'Recycling Rates of Metals', United Nations Environment Programme. 2. Grohol, M., Veeh, C. (2023), 'Study on the critical raw materials for the EU 2023', European Commission. This source was used for fluorite, graphite, phosphates, silicon.	It is challenging to accurately determine the End-of-Life management of CRM products and whether these we recycled or not.	Identify whether a broader dataset is available which covers all CRMs being reviewed.
	Mining concentration	Mining concentration shows how diverse country extraction sources are for CRMs.	% concentration as defined by the Herfindahl-Hirschman index using	1. U.S. Geological Survey. (2023), 'Mineral commodity summaries 2023: U.S. Geological Survey'. This source was used for: palladium,	Mining country data was unavailable in these sources for the following CRMs: bismuth, gallium, germanium,	Identify whether a broader dataset is available which covers all CRMs being reviewed.

3 Appendix 3: Cross-cutting sector database template

Category	Indicator	Rationale	Scoring	Source	Limitations	Future improvements
Supply risk	Mining concentration (continued)		the top three mining countries.	platinum, REEs, rhenium, silicon, strontium, tellurium. 2. Grohol, M., Veeh, C. (2023), 'Study on the critical raw materials for the EU 2023', European Commission. This source was used for the following CRMs: aluminium, antimony, beryllium, boron, chromium, cobalt, copper, fluorite, graphite (natural), lithium, manganese, magnesium, molybdenum, nickel, niobium, phosphates, tantalum, tin, titanium, tungsten, vanadium, zinc, zirconium.	hafnium, indium, iridium, rhodium. There were also discrepancies between the two sources used, such as for nickel.	
	Processing concentration	Processing concentration shows how diverse country processing capacity is in CRM supply chains detailing the top 3 countries by processing %.	% concentration as defined by the Herfindahl-Hirschman index using the top three processing countries.	Grohol, M., Veeh, C. (2023), 'Study on the critical raw materials for the EU 2023', European Commission. This source was used for the following CRMs: aluminium, antimony, beryllium, bismuth, boron, chromium, cobalt, copper, gallium, germanium, hafnium, indium, iridium, lithium, manganese, magnesium, nickel, niobium, rhenium, rhodium, silicon, tellurium, tin, titanium, tungsten, vanadium, zinc.	Processing country data unavailable in this source for the following CRMs: fluorite, graphite (natural), molybdenum, phosphates, REEs, strontium, tantalum, zirconium.	Identify whether a broader dataset is available which covers all CRMs being reviewed.
	Companion metal fraction	Companion metal fraction shows whether a CRM is mined as a primary metal/mineral, or a by-product of another metal/mineral.	% of global production derived as a companion metal	N. T. Nassar, et al. (2015), 'By-product metals are technologically essential but have problematic supply', Science Advances, 1 (3).	Data unavailable for the following CRMs: fluorite, graphite (natural), platinum, phosphates, REEs, silicon.	Identify broader dataset which covers all CRMs being reviewed.

3 Appendix 3: Cross-cutting sector database template

Category	Indicator	Rationale	Scoring	Source	Limitations	Future improvements
Supply risk	Price volatility	Price volatility shows how stable CRM prices are and infers a potential for future fluctuations.	% change in price per CRM (July 2022 – June 2023)	German Raw Materials Agency. (2023), 'Volatility Monitor', Federal Institute for Geosciences and Natural Resources.	Data unavailable for the following CRMs: beryllium, boron, hafnium, iridium, rhenium, strontium. For REEs, an average was used, including neodymium and dysprosium. The time period covered by the source is narrow.	Identify broader dataset which covers all CRMs being reviewed, compile multiple years of data.
	Regulation and sanctions	Regulations and sanctions can apply trade restrictions to CRMs which interrupt supply chains.	Number of export controls or regulations in place per CRM	OECD. (2021), 'Export restrictions on Industrial Raw Materials', OECD.	Approach used assesses number of regulations and sanctions per CRM, not severity or impact.	Complete analysis of the types of regulations and sanctions to better understand risk and impact.
	Governance	Strength of state governance in miner or processor countries can help determine risk of corruption and political instability, amongst other risks to doing business and secure production.	Average of the Worldwide Governance indicators for top 3 mining and processing countries	Kaufmann, D. and Kraay, A. (2023), 'Worldwide Governance Indicators', The World Bank.	N/A	N/A
	Diplomatic relations	Strength of diplomatic relations can be used to assess reliability of supply chains for CRMs from mining and processing countries.	Scoring sourcing countries on UK military alliances (NATO membership), trade agreements (less risk), and arms embargoes (higher risk)	1. NATO member countries 2. UK trade agreements 3. UK arms embargoes	The sub-indicators of military alliances, trade agreements, and arms embargoes do not cover all factors in diplomatic relations. And many countries have none of these bilateral relations with the UK, to mitigate this no relations will not change a risk score.	Analysis could include a wider range of sub-indicators.
	Economic development (mining country)	Economic development can be used as a proxy for infrastructure development in a mining country, which can impact on supply chain security.	GNI per capita in USD for top 3 mining countries	The World Bank. (2023), 'GNI Per Capita, PPP', The World Bank.	Economic development may not always be a reliable proxy for infrastructure development in a mining country.	N/A
	Economic development (processing country)	Economic development can be used as a proxy for infrastructure development in a processing country, which can impact on supply	GNI per capita in USD for top 3 processing countries	The World Bank. (2023), 'GNI Per Capita, PPP', The World Bank.	Economic development may not always be a reliable proxy for infrastructure development in a processing country.	N/A

3 Appendix 3: Cross-cutting sector database template

Category	Indicator	Rationale	Scoring	Source	Limitations	Future improvements
Supply risk	ISO standardisation	ISO standardisation helps outline best practice for CRM production.	Yes / No	ISO/TC 345: specialty metals and minerals. ISO/TC 79: light metals ISO/TC 183: copper, zinc, nickel ISO/TC 333: lithium ISO/TC 132: ferroalloys ISO/TC 298: rare earth	Unavailability of ISO standards may not equate to heightened risk of poor production methods.	N/A
Environme-ntal and social risk	CO_2 emissions	CO_2 emissions increase the environmental impact of mining a CRM and the total Scope 3 emissions of a company.	Global warming potential (kg CO2eq / kg)	Nuss, P., Eckelman, M. (2014), 'Life Cycle Assessment of Metals: A Scientific Synthesis', PLoS ONE 9 (7): e101298.	Data unavailable for the following CRMs: fluorite, graphite (natural), phosphates, REEs. Data is from 2014, so CO2 emissions associated with a CRM could have changed. Data quality is unclear.	Identify whether a broader dataset is available which covers all CRMs being reviewed. Or undertake detailed LCA with real world data which identifies impact of specific country pathways
	Water pollution	Water pollution can impact CRM producer countries areas by making water unsafe to drink and damaging soil fertility.	% of wastewater treated for top 3 mining and processing countries	Yale Center for Environmental Law and Policy. (2022), 'Environmental Performance Index', Yale University.	Data refers to water pollution in countries where CRMs are mined and processed, rather than analysing water pollution caused by producing a specific CRM.	Identify whether a more focused dataset is available which analyses water pollution directly caused by CRM production.
	Water depletion	Water depletion can impact water availability in surrounding communities for uses such as agriculture.	WRI Aqueduct, top 3 mining and processing countries	World Resources Institute. (2022), 'Aqueduct', World Resources Institute.	Data refers to water depletion in countries where CRMs are mined and processed, rather than analysing water depletion resulting from the production of a specific CRM. And is a measure of mining operations taking place in countries with low water security.	Identify whether a more focused dataset is available which analyses water depletion directly caused by CRM production which could be combined with this set to understand baseline water scarcity and the impact of CRMs.
	Water scarcity	Water scarcity can impact a CRM producer's ability to continue operations if water is unavailable.	WRI Aqueduct, top 3 mining and processing countries	World Resources Institute. (2022), 'Aqueduct', World Resources Institute.	Data refers to water scarcity in countries where CRMs are mined and processed, rather than analysing specific regions where CRM production is located.	Identify whether a more focused dataset is available which analyses water scarcity in regions where CRM production is located.

3 Appendix 3: Cross-cutting sector database template

Category	Indicator	Rationale	Scoring	Source	Limitations	Future improvements
Environmental and social risk	Ecosystem loss	Ecosystem loss can destroy habitats, reduce effectiveness of carbon sinks, and weaken natural defences against extreme weather. Countries with high scores have a poorer record of managing eco-system loss increasing risk of further losses through mining.	75% weighting for deforestation ; 25% weighting for grassland and wetland loss (based on top 3 mining countries)	Socioeconomic Data and Applications Center. (2022). 'Environmental Performance Index', NASA.	Data refers to ecosystem loss in countries where CRMs are mined.	Identify whether a more focused dataset is available which analyses ecosystem loss directly caused by CRM mining.
	Biodiversity	Destruction of biodiversity can have significant environmental and economic impacts on a country.	Total mining-related biodiversity loss in top 3 mining countries	Cabernard, L.,. Pfister, S. (2022). 'Hotspots of Mining-Related Biodiversity Loss in Global Supply Chains and the Potential for Reduction through Renewable Electricity', Environ. Sci. Technol. 56 (22), 16357–16368	Data unavailable for the following CRMs: Bismuth, Gallium, Germanium, Hafnium, Indium, Iridium, Rhodium.	Identify whether a broader dataset is available which covers all CRMs being reviewed.
	Child labour	Child labour in supply chains represents a significant regulatory and reputational risk for companies and hinders the basic human rights of children.	% of children aged 5-17 years engaged in child labour in top 3 mining and processing countries	UNICEF. (2023) 'Child Labour', UNICEF.	There are gaps in the data for a large number of countries. Some countries have not been updated since 2016. Data is not specific to child labour in CRM production.	Identify whether a broader dataset is available which covers all countries and focuses on CRM production.
	Forced labour	Forced labour represents a significant legal risk for companies under the Modern Slavery Act and hinders basic human rights.	People in forced labour per 1000. in top 3 mining and processing countries	Walk Free. (2023) 'Global Slavery Index', Walk Free.	It is highly likely that a portion of forced labour is not reflected in the data. Data is not specific to forced labour in the CRM production.	Identify whether a more focused dataset is available which analyses forced labour in CRM production.

4 Appendix 4: Projects and Infrastructure summary

Refining | Smelting | Mining | Recycling | Metal production

Company	Activity	Commodity	Status	Contributions to UK supply chains
Alvance British Aluminium Ltd		Aluminium	Operational	A £94m investment is set to double the capacity of the new recycling and casting facility to 80,000 tonnes per year by 2024.
Ionic Technologies International Ltd		REE	Pilot	A patented process has been developed to recycle REEs in magnets, meeting specifications for EVs, wind turbines, military, and aerospace, with a demonstration plant built to process ore samples.
Green Lithium Refining Ltd		Lithium	Planned	Planning permission has been granted for a new refinery, which is anticipated to produce 50,000 tonnes of battery-grade lithium hydroxide per annum, which will enable the production of 70 GWh battery equivalent.
Peak Rare Earths Ltd		REE	Planned	A lease deal has been reached for the proposed site, where REEs will be transported from the Ngualla Rare Earth Project in Tanzania to the Teesside Refinery.
Altilium Metals Ltd		Lithium-ion batteries	Planned	Altilium uses hydrometallurgical techniques to recover battery materials from end-of-life EV batteries and mine tailings, developing green processing technologies and recycling infrastructure.
Pensana Plc		REE	Under construction	Ozango Minerals, a subsidiary of Pensana Plc, has received approval to mine REEs from the Longonjo Rare Earths project in Angola, with plans to export up to 40,000 tons of mixed rare earths sulphate from the mine for processing at its refining site in the UK.
Ross & Catherall Ltd		Cobalt, nickel, and iron alloys	Operational	A new 4000kg capacity Vacuum Induction Melting Furnace due to be installed following a £7m investment.
Less Common Metals Ltd		Superalloys	Operational	In September, a strategic supply agreement was made with Rainbow Rare Earths to provide magnet materials for the manufacturing of magnets, complex alloys, and metals.
Techemet Ltd		Platinum, palladium, rhodium, gold, silver	Operational	£2.1m was invested in a storage facility in Northern Ireland to collect catalytic converters.
Fenix Battery Recycling Ltd		Lithium-ion batteries	Planned	A new battery recycling facility has opened, which will specialize in recycling ELVs, with the company receiving significant grant, to develop innovative technology for cleaner and more sustainable lithium-ion battery recycling.
Veolia UK Ltd		Lithium-ion batteries	Planned	Veolia currently has four sites with the capacity to process 30,000 metric tons of batteries, with plans to increase recycling capacities with around 10 other site projects in multiple locations, and is scaling up its activities in Europe, Asia, and North America.
HyProMag Ltd		REEs	Pilot	HyProMag, a company owned by Maginito Limited, a subsidiary of Mkango Resources Ltd, is developing a £5.3 million facility, with a minimum production capacity of 100 metric tons per year. The facility is expected to have a minimum production capacity of 100 metric tons per year.

4 Appendix 4: Projects and Infrastructure summary

Refining | Smelting | Mining | Recycling | Metal production

Company	Activity	Commodity	Status	Contributions to UK supply chains
Johnson Matthey Plc	Refining	Primary: Platinum, palladium Secondary: Rhodium, ruthenium, iridium	Operational	Johnson Matthey is investing £80m in a gigafactory to scale the production of hydrogen fuel cell components and electrolysers, and has received a £400m Government-backed loan for R&D in sustainable technologies, including hydrogen.
Tungsten West Plc	Mining	Primary: Tungsten Secondary: Tin	Under construction	Tungsten West plc owns the Hemerdon Mine, the second-largest resource in the world, and is focused on restarting production to meet the increasing demand for strategic metals, including tungsten and tin, with a 27-year life of mine and an average annual production of 2,900t of tungsten and 310t of tin, positioning TUN as the largest tungsten producer in the Western World.
British Lithium Ltd	Refining	Lithium	Pilot	British Lithium was granted a £2.9m research and development grant, and a £2m scale-up readiness validation grant. Imerys British Lithium operates a £4 million lithium pilot plant in Cornwall to extract battery-grade lithium from mica granite; British Lithium have entered a joint venture with Imerys and are progressing towards full-scale lithium carbonate production by 2028, capable of producing over 20,000 tonnes of lithium carbonate per year, for 30 years.
Cornish Lithium Plc Trelavour	Mining	Lithium	Feasibility with demonstration plant under construction	The Trelavour hard rock project is expected to have a 20-year life of mine and generate around £800 million for the local economy.
Cornish Lithium Plc United Downs & Twelveheads	Mining	Lithium	Test facility plus pilot for direct lithium extraction technologies	Cornish Lithium's United Downs site is their flagship exploration site for lithium-enriched geothermal waters, and the company successfully drilled an exploration borehole in the Twelveheads area, encountering permeable structures containing lithium-enriched geothermal waters with an average grade of around 100 parts per million below 1,700m.
Cornish Metals Ltd	Mining	Primary: Tin Secondary: Copper	Feasibility with Water Treatment Plant under construction	South Crofty has the fourth-highest grade tin Mineral Resource globally with multiple shafts that can be used for future operations. The South Crofty project has an underground permission valid until 2071, planning permission to construct a new process plant, and a permit from the Environment Agency to dewater the mine.

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